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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
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MEETINGS

of the

American Institute of Electrical Engineers

(See Announcements This Issue)

WINTER CONVENTION, New York, N. Y.
February 13-17, 1928

ST. LOUIS REGIONAL MEETING, District No. 7
March 7-9, 1928

BALTIMORE REGIONAL MEETING, District No. 2
April 17-19, 1928

NEW HAVEN REGIONAL MEETING, Northeastern
District No. 1, May 1928

SUMMER CONVENTION, Denver, Colo.
June 25-29, 1928

MEETINGS OF OTHER SOCIETIES

The American Society of Mechanical Engineers, Annual Meeting, New York, N. Y., December 5-8, 1927

American Physical Society, Nashville, Tenn., December 28-30, 1927

American Road Builders' Association, Cleveland, Ohio, January 9, 1928

Institute of Radio Engineers, Third Annual Convention, New York, N. Y., Jan. 9-11, 1928

American Society of Civil Engineers, New York, N. Y., January 18-20, 1928

Midwestern Engineering and Power Exposition, Coliseum, Chicago, February 14-18, 1928

American Institute of Mining and Metallurgical Engineers, New York, N. Y., February 20-23, 1928

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OF THE
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Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLVI DECEMBER, 1927 Number 12

A War Memorial for American Engineers

Approximately seventy-five members of the American National Societies of Civil, Mining, Mechanical and Electrical Engineers died in service abroad during the World War. No memorial to these engineers has been set up. A unique and fitting possibility was discovered during the summer.

While Dr. Edward Dean Adams, member of the American Society of Civil Engineers and the American Institute of Electrical Engineers, was in Belgium last June as delegate of several American Engineering Societies to the celebration of the five hundredth anniversary of the University of Louvain, he learned that the new Louvain Library building being given by Americans lacked two important features, a clock and a carillon for its tower. No Belgian tower is complete without them. For centuries the bells of the "singing towers" of the "Low Countries" have inspired, entertained and educated the people. America's beautiful gift must be complete when dedicated next May or June.

Dr. Adams at once saw the opportunity for a peculiarly acceptable expression of good will from American engineers to their Belgian friends, and for a beautiful, perpetual memorial to American Engineers who had given their lives outside their country in the great war. He secured the privilege of providing the clock and the carillon as gifts from American engineering societies. The time is short, but sufficient for prompt action. Approval of the project has been given by the Joint Conference Committee, composed of the Presidents and the Secretaries of the Founder Societies. The fund of $80,000 has been underwritten. This will provide a clock with four faces, a three-octave carillon of thirty-six bells, installed and guaranteed for ten years, and an ample endowment for perpetual operation and maintenance.

The tower is square and the four clock faces will typify the four Founder Societies. On an inside wall of the tower tablets to the American engineers who made the supreme sacrifice may be erected.

An opportunity is now offered to each member of these societies and of the families of the deceased to contribute to this joint fund any amounts, from five dollars up, which they may choose, by sending checks, drafts, or post-office money orders to United Engineering Society, at 29 West 39th Street, New York, *before February 1, 1928.* The names of all subscribers will be engrossed in a beautiful memorial volume to be deposited in the Library. A copy of this book will be placed in the office of each Society.

Here is both privilege and patriotic obligation fortunately reserved for American engineers to place the crown upon a beautiful permanent contribution to European higher learning, including the engineering and scientific branches. The project has grown out of the greatest relief enterprise connected with the war, organized and administered under the masterful leadership of American engineers. It is fitting that American engineers should put the finishing touches to this gift of peace.

Committee on War Memorial to American Engineers

George W. Fuller	Representing the Civil Engineers
Arthur S. Dwight	Representing the Mining Engineers
Charles M. Schwab	Representing the Mechanical Engineers
Arthur W. Berresford	Representing the Electrical Engineers
George Gibbs	Representing United Engineering Society
Edward Dean Adams *Chairman*	Representing Engineering Foundation

Following is a list of members of the Institute who died abroad while in the service of the United States, or of her Allies, together with their last business affiliation:

Anderson, E. G., H. L. Doherty Co., 60 Wall Street, New York, N. Y. "Died July 15, 18 in a hospital in France as a result of wounds."

Bishop, Remsen, The Electrical Department, Ford Motor Company, Detroit, Michigan. "Killed in action, June 1918."

Brooks, H. N., Consulting Engineer, 1390 Old Colony Bldg., Chicago, Illinois. "May 1918. Died recently in France of pneumonia."

Carr, Lucien, 3rd, The Hartford Electric Light Co., Hartford, Connecticut. "Died of influenza in France, November 11, 1918."

Day, R. F., Day & Zimmerman, Philadelphia, Pa. "Killed at Clermond-Ferrond, France, September 25, 1918."

Donnohue, J. J., The Utah Power and Light Co., Salt Lake City, Utah. "Killed in an airplane accident in France, June 26, 1918."

Duffy, F. J., The D. L. & W. R. R. Co., Scranton. Pa, "Killed in action, France, August 17, 1918."

Macindoe, G., Canterbury College, Christchurch, N. Z. "Killed in action in Belgium, October 4, 1917."

Moore, C. J., Oklahoma A. & M. College, Stillwater, Okla. "Wounded in action at Fromerville, France, on October 16. Died on October 18, 1918."

Thompson, A. R., The Pacific Gas & Electric Co., San Francisco, Calif. "Killed in auto accident in France, September 17, 1918."

Shanks, D. A., Howick, Quebec, Canada. "Reported missing on September 21, 1918—a month later he was reported dead."

The Institute would be glad to receive information concerning engineers not included in the above list, who died abroad, whether members or non-members of an engineering society. Other engineering societies are making similar efforts to obtain information regarding engineers who died in service abroad.

FORM OF SUBSCRIPTION

To The Committee on War Memorial
to American Engineers,
29 West 39th Street, New York.

I (or we) subscribe $.................... to the fund of the Founder Societies for giving to the University of Louvain the clock and the carillon for the tower of its Library as a memorial to the American Engineers who died abroad in the service of their country or its allies in the World War. I (or we) will make payment before February 1, 1928.

(Signature)..

(Address)..

Date..

Checks, drafts or post-office money orders should be made payable to United Engineering Society. These gifts being for educational purposes, may be deducted from Federal income tax returns.

Some Leaders of the A. I. E. E.

George Anson Hamilton, a Charter Member of the Institute, its first Vice-President (1884-86) and its National Treasurer since 1895, was born in Cleveland, Ohio, December 30, 1843. While still a mere boy, he evidenced great interest in electricity and its application, building a telegraph line (on a very modest scale) at Limaville, O., he, himself, setting the poles, affixing the insulators and even devising a lathe with which to make his own apparatus. This same episode had much to do with determining his career. In 1861 he became a messenger at Salem, O., but two months later was made manager of the Atlantic & Great Western Railroad office at Ravenna, to which point the line had just been completed. Illness in 1863 forced him to withdraw, but upon his recovery he went to Pittsburgh as operator and manager of the Inland Company. In 1865 he removed to Franklin, Pa., to become manager of the United States Telegraph Company's office; but he returned to Pittsburgh in 1866, and as chief operator and circuit manager, he remained there until 1873 when his company was absorbed by the rapidly growing Western Union. Opportunity was now offered for experimental work and he accepted a position as assistant to Professor Moses G. Farmer, of Boston, engaged in the manufacture of general electrical apparatus and machinery. This work gave him valuable practical knowledge of mechanics, and he also participated in many important experiments and investigations not only in the field of telegraphy but other electrical developments of the time. His diligence and success attracted attention and in 1875 he was called to New York to assume new duties as assistant electrician to the Western Union Company. Much of the two years following was spent in company with Mr. Gerritt Smith, in establishing and maintaining the first quadruplex telegraph circuits to be put into operation. He was also with Mr. Smith the first to introduce the system in England, and upon his return to America, carried out experiments preliminary to establishing the Wheatstone high-speed automatic system in this country. On the repair expedition of Key West-Havana cables in 1876, Mr. Hamilton was appointed chief electrician. To him also may be attributed many of the arrangements made for apparatus improvements introduced by the Western Union Company. In fact it was to afford his inventive genius a field of broader scope and application that he later joined the Western Electric Company in response to an urgent invitation from that Company's officers. Here he was given the supervision and care of the company's department for the production of fine electrical instruments, and here he remained until his retirement in 1909. Mr. Hamilton is a member of the British Institution of Electrical Engineers, la Société Française des Electriciens, and la Société Francaise de Physique, la Société Belge d'Astronomie.

Foreign Research Laboratory For Short-Circuit Tests

The lack of facilities for the practical testing of large oil switches has been discussed frequently in this country as well as abroad but there has been no suitable testing laboratory available of the necessary size. The Berlin Municipal Electricity Works, have made a strenuous effort to establish suitable testing facilities. A committee of leading men in the electrical industry under the chairmanship of General Director Coninx of Nürnberg, and with the special cooperation of Director Peucker of Berlin, has drawn up regulations for a cooperative plan. Almost all of the more important firms in this field have promised their cooperation.

A company "Versuchsanstalt für Kurzschlusswirkungen" was formed last summer, for which Prof. Matthias was selected as temporary manager. The association is to work in close cooperation with the Studiengesellschaft für Hochstspannungsanlagen, which is similarly organized. It will surpass any other installations in peak load, and by the erection of several test stands and rapid exchangeability of the test objects as well as by suitable switching, will permit an intensive and multiple utilization of the arrangements for research with smaller loads. With such multiple use, the measuring arrangements will be suitable for the most varied problems, for example, for the measurement of sudden pressure impacts, accelerations, heating, amounts of gas and the like. These arrangements are available for all investigations. Depending on the amount of capital subscribed, the Institute will give individual members of the association a certain time for development work or acceptance tests of individual interest. The rest of the time will be spent on investigations of general interest.

Abridgment of

Railway Inclined Catenary Standardized Design

BY O. M. JORSTAD[1]

Associate, A. I. E. E.

Synopsis.—A description is given of a new method of overhead contact design, the "ideal inclined catenary". This is based on an originally discovered tension and weight relation formula. A proof of the formula is given and other characteristics of the design are mathematically analyzed.

A number of railroads now using inclined catenary is listed and data on the weights and tensions of their overhead constructions are given for comparison purposes with the "ideal."

The necessity of making a definite selection of a proper contact wire tension in any inclined catenary design is indicated and that this, together with the use of the design formula, leads to standardization of overhead systems is pointed out.

A RAILROAD track alinement is made up of a succession of tangents and curves. The overhead contact system in an electrification must be designed to follow the alinement so that the current collector of the car or locomotive will always make contact in a satisfactory manner.

Many types of overhead contact systems have been designed and applied on the many electrified railroads throughout the world. On tangent sections they are practically all similar in one respect, *i. e.*, their catenary hangers are vertical. The curve constructions, however, generally speaking, may be divided into two classes, one with hangers vertical as on tangent and the other with hangers inclined across the track. The vertical hanger type is called, by some, the polyhedral type and by others the chord type, as the catenary construction is pulled into a series of straight lines or chords over the track by pull-offs from a back-bone or pull-off posts. The inclined hanger type pulls the contact wire into a position over the curved track by inclining the hangers and thus causing them to function as combined pull-offs and hangers. Back-bones and pull-offs, except on the sharper curves, are usually omitted in the inclined catenary construction.

Chord construction is an adaptation of tangent construction to curves. Likewise, the more usual inclined construction has heretofore been the result of displacing the messenger of the correlated tangent construction laterally. In the United States, both types are in general use with inclined catenary the most common on main line electrifications. In other countries, however, the chord type has been the most favored. The following is a partial list of users of inclined catenary in this and other countries:

The New York, New Haven and Hartford Railroad Co.

New York, Westchester and Boston Ry.,

Boston and Maine Railroad.

Pennsylvania Railroad,

Norfolk and Western Ry.,

Virginian Ry.,

Detroit, Toledo and Ironton Railroad.

Chicago, North Shore and Milwaukee Railroad Co.,

Canadian National Rys.,

Lancaster, Morecambe and Heysham Railroad in England,

Midi Railroad in France.

This list indicates that the inclined catenary is a practicable construction and that in every electrification of the immediate future it will in all probability come up for consideration. It also strongly indicates that an inclined catenary of some description will be a future standard overhead.

The good qualities of the inclined construction may be partially summarized as follows: It is artistic and makes a strong appeal to the esthetic sense. It is economical of material in that it employs two wire members to do the work of the usual three or four in the chord type. It has inherent automatic tension characteristics and above all it supplies a contact line that approaches most closely the ideal desired, *i. e.*, uniform flexibility. The greatest obstacle in the way of its more general use has been the comparative complexity of methods of design.

As stated above, the present forms of inclined catenary curve construction were developed from the correlated tangent construction and consequently acquired similar tensions and sags for similar lengths of spans. In the design of the tangent construction, there has been no fixed rule for determining the relative values of the various factors of design, tension, weight, sag, etc., of messenger and contact. The object sought was a maximum span with sags selected to keep the contact wire from being displaced by wind and leaving the collector. Such requirements resulted in a great variety of tangent catenary designs, each one depending on local and special conditions. The resulting related inclined catenary curve constructions were not entirely satisfactory from the designer's standpoint as there was difficulty in securing proper alinements but they were made operative and were usually a great improvement over previous chord constructions, particularly on multi-track sections.

There is now available, however, the discovered formula,

$$T_m/T_c = W_m/W_c \qquad (1)$$

1. General Engineering Dept., Westinghouse Elec. & Mfg. Company, East Pittsburgh, Pa.

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927. Complete paper contains four appendixes of mathematical proof. Copies upon request

which provides a basis for a simplified and precise design of inclined catenary. In the formula, W_c = weight of contact wire in lb. (kg.) per linear ft., T_c = tension of contact wire in lb., W_m = weight of messenger wire in lb. (kg.) per linear ft., and T_m = tension of messenger wire in lb. In this design, the contact wire is practically parallel to the center line of track and all hangers in any given curve are parallel, *i. e.*, they make the same angle with the vertical. Also it must be noted that it is the combination of the weight and tension relation indicated by the formula and the approximate parallelism of contact wire with center line of the curved track that provides what may be called an ideal inclined catenary. With one of the two conditions absent, an ideal inclined catenary is not secured.

It should also be noted that this ideal combination of conditions can be secured only at some one selected design temperature. A change in temperature tends to modify both of the combination factors in a construction, as T_c/T_m does not usually stay constant over a range of temperature and the contact wire distorts either vertically or horizontally with the least

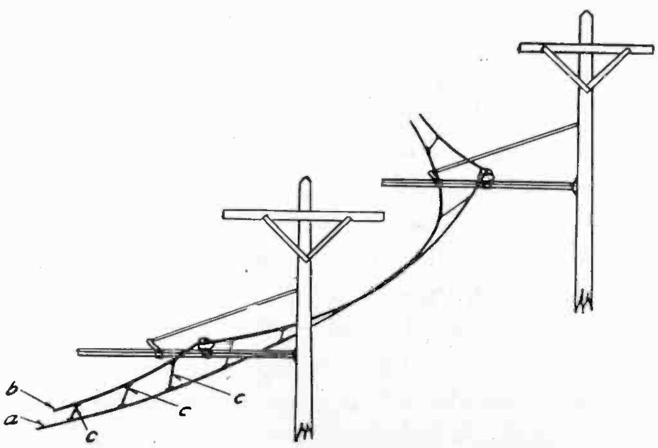

Fig. 1—Showing Inclined Catenary in Perspective

change in temperature. This variation of tension with temperature is, however, a characteristic of all non-automatic catenary constructions.

Also, any loss in weight of the contact wire after construction due to wear by collector causes a departure from the ideal design conditions. The loss in weight of contact is accompanied by a corresponding loss in tension and thus the formula is apparently satisfied. The loss in weight of contact wire, however, causes the tension of messenger to decrease due to its decreased load. This causes the messenger to rise, pulling up the contact wire at the middle of span with consequent distortion from its original position of parallelism to center line of track. Distortion due to loss of weight with wear, however, is common to all contact systems.

A demonstration of the truth of the formula may be made as follows. Fig. 1 is a sketch in perspective of the usual inclined catenary. Here *a* is the contact wire, *b* the messenger and *c*, *c*, the inclined hangers. Fig. 2 is a plan view of an ideal inclined catenary span with zero length of shortest hangers. The contact wire *a* is a parabola and the curve *f*, the projection of the messenger on the horizontal plane of contact wire, is also a parabola.[2] The two parabolas are tangent at their vertices.

The ideal contact line or wire is defined as the wire under tension which lies in a horizontal plane and has the form of a parabola whose horizontal sag for a given span and curve is equal to the middle ordinate of the circular arc of the same span. For the usual spans and usual degrees of curvature there is practically no difference in the tensions or positions of the wire in the form of a parabola or an arc of a circle.[3]

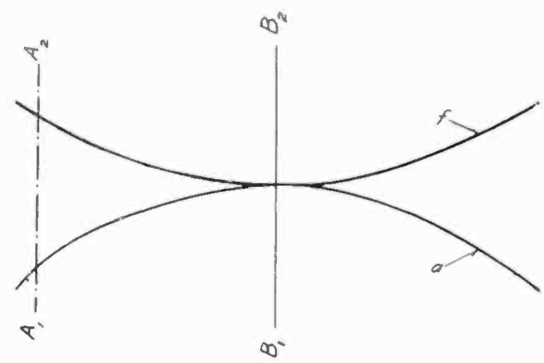

Fig. 2—Plan View of Ideal Inclined Catenary Construction

$A_1 - A_2$ Fig. 2 is a vertical plane through the messenger and contact parallel to the principal axis $B_1 B_2$ of the contact parabola. In Fig. 3 the triangle $g\,h\,i$ is a projection horizontally on the vertical plane $A_1 - A_2$ of Fig. 2 of the inclined catenary construction.

In Fig. 3:

$g\,h$ = horizontal sag of contact parabola,

$g\,i$ = hanger in the plane of projection,

$h\,i$ = sag of messenger.

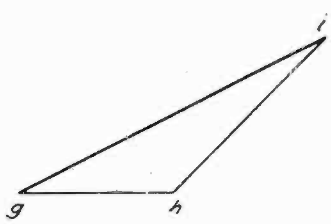

Fig. 3—Projection Horizontally of Ideal Inclined Catenary Construction on Vertical Plane $A_1 A_2$ of Fig. 2

Fig. 4 is a projection similar to Fig. 3 but with the following additional construction:

$g\,h$ is extended horizontally to o,

$i\,o$ is dropped vertically from i to o,

a vertical is constructed through g,

$i\,m$ is extended horizontally from i to meet vertical at m,

the diagonal $i\,h$ is extended to meet vertical at k.

In the triangle $m\,i\,g$ of Fig. 4, $i\,g$ has the slope of the hanger and if its length is assumed to represent the

2. See Appendix I.

3. See Appendix IV.

force on the hanger due to the dead load of contact wire and horizontal load caused by tension in contact wire then the latter two forces are represented respectively by the other two sides of the force triangle *m g* and *m i*.

Likewise in triangle *m i k* of Fig. 4, *i k* has the slope of the messenger and as *m i* represents the horizontal load on the messenger due to tension in contact, the other two sides of the triangle will represent the other

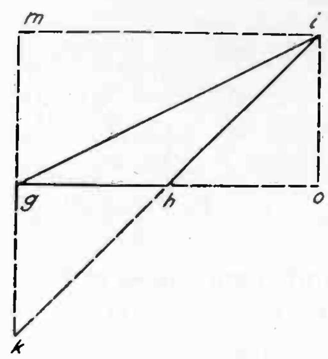

Fig. 4—Projection of Fig. 3 With Additional Construction Lines

two forces on the messenger, *m k* the total dead load acting vertically and *i k* the resultant load on messenger acting in the direction of slope of messenger.

Therefore

$m\,k = W_c + W_m$, weight of contact plus weight of messenger, and since $m\,g = W_c$ = weight of contact (2)

then

$$g\,k = W_m = \text{weight of messenger} \quad (3)$$

and

$$g\,k/m\,g = W_m/W_c \quad (4)$$

The two triangles in the Fig. 4, *g h k* and *h o i*, are similar since their corresponding angles are equal.

Therefore

$$g\,h/h\,o = g\,k/i\,o \quad (5)$$

But

$$i\,o = m\,g, \text{ by construction} \quad (6)$$

Therefore

$$g\,h/h\,o = g\,k/m\,g \text{ from 5 and 6} \quad (7)$$

Also

$$g\,h/h\,o = T_m/T_c \text{ see Appendix III} \quad (8)$$

Therefore

$$T_m/T_c = W_m/W_c \text{ (axiomatic from (4), (7) and (8))} \quad (9)$$

It has thus been demonstrated that the ideal inclined catenary construction with zero length of shortest hanger is a true construction and that the relation of weights and tensions of members is as given in the formula.

The usual inclined catenary, however, has a shortest hanger of some length. If the contact line of such usual catenary is ideal,[4] it also has parallel hangers and the formula will also show the relation of its weights and tensions.

4. See previous definition.

This can be demonstrated by considering Fig. 5. On Fig. 5, *g h i* is the *g h i* of Fig. 3; *g s p h* is another figure showing the projection of the more usual inclined catenary with shortest hanger *h p* of some length. The only difference between the ideal inclined catenary *g h i* and the usual inclined catenary illustrated is in the length of hangers. The other factors in the two are identical, weight of contact, tension of contact, weight of messenger and tension of messenger. Consequently, the usual inclined catenary with ideal contact line and parallel hangers will be in agreement with the formula. And conversely, if weights and tension are chosen in accordance with the formula, an ideal inclined catenary results if the contact line is made ideal.

In demonstrating the formula it has been assumed that the hangers were without weight. Practically, they will have some weight, this usually approximating five per cent of contact and messenger weight. This weight will have an effect on the actual slope and sag in practical construction and must be provided for. If the hanger weight is included by prorating it and including with contact and messenger weights, the ratio of weights and consequently of tensions in the formula is not changed so that if a basic contact tension is selected, the messenger tension will be fixed regardless of whether hanger weights are considered or not. Therefore, in preliminary determination or selection of messenger tension, hanger weights can be safely ignored.

In determining slopes of hangers and slopes of messenger and sag of messenger, however, the weights of hangers must be taken into consideration. Such consideration, however, will not destroy the value of the formula in practical applications as the distortion due to the hanger weights in the extreme case, *i. e.*, the case where the shortest hanger is assumed to have zero length, is practically negligible.

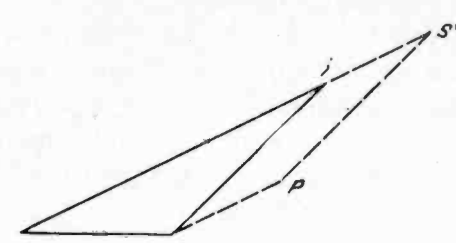

Fig. 5—Projection of Fig. 3 with Projection of Inclined Catenary with Lengthened Hangers

To assist in applying the formula in design work the nomogram in Fig. 6 is given. By its use the tensions for various messengers of different weights can be quickly and accurately determined. Likewise, the effect on messenger tension of changes in contact characteristics in the preliminary design can be readily determined. The index lines show that a four naught (106-sq. mm.) copper contact wire weighing 0.641 lb. per ft. (0.956 kg. per m.) tensioned to 2500 lb. (1135 kg.)

from the tangent to the body of the curve. This section of the overhead is somewhat similar to a spiraled section of the running track. With an inclined catenary designed according to formula, transition design is greatly simplified as the selection of hangers of suitably varying angle and length becomes a relatively simple process by means of the diagram of Fig. 7.

Usually a simple design is economical and results in lowest cost for the duty performed. It is not proposed to demonstrate with mathematical exactness that the formula design of inclined catenary results in lowest over-all construction costs. The following analysis would indicate, however, that this is practically true.

Assuming equally good design of supporting structures, the combination of minimum loads consistent with minimum dimensions of catenary structure, both vertical and horizontal, should result in minimum supporting structures. If a messenger tension greater than that demanded by formula is selected by the designer, there will of course be a greater side load on the structures than if the formula were followed, since the side load varies directly as total wire tension. The dimensions may be reduced vertically somewhat but probably will not be reduced horizontally because of the distortion of the contact wire from the position parallel to center line of track.

If a messenger tension less than that of formula is selected in order to diminish the side load, the vertical and horizontal dimensions of catenary and of supporting structure will be increased as the sag is increased and although there may be a smaller effective side load, overcoming the distortion of the contact and messenger will require additional pull-offs and other changes such as auxiliary back-bones or more frequent supports with the probable net result of increased cost.

One of the greatest economic advantages of designing according to the formula is the resultant easy erection of the wires. All parts fit together naturally and there are minimum secondary stresses. The construction can be handled like a truss with members designed and connected properly, as compared to a truss in which members are not of proper length and in which the loads are carried eccentrically by the members. Cables are of course much more flexible than truss members and hence can be more easily pulled into connection with other members but nevertheless secondary stresses and distortion result with inexact design and must be provided for in the original design or as later experience dictates. With the inclined designed as per formula, the parts fit and come together easily so that the time and labor of erection and later maintenance become a minimum.

Design based on the formula also makes variations of the simple inclined catenary relatively easy. Double catenary, either with double contact or messenger or both, and staggered catenary on curve and tangent are examples of such variations. Furthermore, as is often desirable, if a stretch of chord construction is required, it can be readily introduced without complications between sections of inclined catenary.

The formula would appear to handicap design in that it selects but one messenger tension value and thus fixes the dimensions of the catenary on tangent as well as on curve after the other three factors, contact weight, contact tension, and messenger weight, are settled upon. There should be no objection to the limitations imposed if a reasonable construction results. If the resulting construction is not considered reasonble, it is still possible to change the other factors of design such as contact material and tension as well as messenger material and resulting tension in order to better satisfy tangent conditions.

The result of following this method of design will be the eventual selection of several contact weight and tension conditions as standards so that for similar service on comparable lines there will be available a suitable standard. Such a condition should enable sound comparisons to be readily made of operating conditions on such lines.

Assuming that a contact wire of a given weight and tension relation is installed as tentative standard practise, the inclined catenary construction has an inherent tendency to maintain this relation of weight and tension constant for a given temperature over a period of years, as the operating slope of hangers and position of contact wire over track depend on such relation being kept constant. The tension of the contact wire is a much more important design factor in any inclined catenary than in chord construction. It is in fact the basic or starting factor. In the chord type of construction the tension of the contact wire may vary over a wide range and not produce any noticeable effect on the shape of the construction. Two lines or sections of chord construction may appear exactly alike and yet have very different contact tensions and hence different collecting characteristics. This is not so of inclined catenary constructions. If they are otherwise alike, their contact tensions are also alike and consequently their collecting characteristics will be alike and they will stay alike with similar temperatures. True operating comparisons can then be made of such overheads under the same or differing services with the gradual result of continually improving the standards. The economic result of such a condition should be very satisfactory. It would only be a matter of time before the most economically designed and operated line or lines for certain conditions would be found.

It is interesting and valuable to use the formula as a check on already existing and operating inclined catenaries. Investigation shows that practically all lines heretofore installed depart more or less from this criterion, some more than fifty per cent. This might indicate one of two conditions. Either the formula application is not practically necessary and inclined catenary is very adaptable or present inclined catenary construction designs are subject to refinement.

Data showing the departure from the formula on certain important lines already installed are as follows:

Canadian National Railways. From data which appeared in the *Railway Age*, May 2, 1925, in article, "New Catenary Construction on the Canadian National," and elsewhere, the following values were secured:

$$W_m = 0.745 \text{ lb.},$$
$$W_c = 0.641 \text{ lb.},$$
$$T_c = 2400 \text{ lb.},$$
$$T_m = 3600 \text{ lb.}$$

T_m as per formula should be 2790 lb. Hence, tension used is 30 per cent higher.

Pennsylvania Railroad. Philadelphia to Paoli Electrification. From data in *The Electric Journal*, February, 1916:

$$W_m = 0.510 \text{ lb.},$$
$$W_c = 0.509 + 0.320 = 0.829 \text{ lb.},$$
$$T_c = 3000 + 1000 = 4000 \text{ lb.},$$
$$T_m = 3500 \text{ lb.}$$

T_m, according to formula, should be 2470 lb. Hence, tension used is 42 per cent higher.

New York, Westchester, and Boston Railway. Data in Sidney Withington's article, *Journal of Franklin Institute*, Dec., 1914, are as follows:

$$W_m = 0.810 \text{ lb.},$$
$$W_c = 0.641 + 0.558 = 1.199 \text{ lb.},$$
$$T_m = 4900 \text{ lb.},$$
$$T_c = 3500 \text{ lb.}$$

T_m, according to formula, is 2370 lb. Hence, tension used is 107 per cent higher.

N. Y., N. H. & H. R. R. Danbury Branch. From page 313 of *Electric Railway Journal* for August 29, 1925:

$$W_m = 0.668 \text{ lb.},$$
$$W_c = 0.641 + 0.641 = 1.282 \text{ lb.},$$
$$T_c = 1600 + 1815 = 3415 \text{ lb.},$$
$$T_m = 3900 \text{ lb.}$$

T_m, according to formula, should be 1785 lb. Hence, tension used is 118 per cent higher.

Midi Railway of France. From data on page 175 of *Le Genie Civil*, August 25, 1923, the following information is obtained:

$$W_m = 0.65 \text{ kg.},$$
$$W_c = 0.89 + 0.89 = 1.78 \text{ kg.},$$
$$T_c = 700 \text{ kg.} + 700 \text{ kg.} = 1400 \text{ kg.},$$
$$T_m = 1350 \text{ kg.}$$

According to formula, T_m should be 510 kg. Hence, tension used is approximately 164 per cent higher.

A number of lines has been designed in accordance with the formula and several have been constructed and are in process of construction. Model spans have also been built. The results indicate that the formula is a very satisfactory and practical guide. The usual inclined catenary is a practical though somewhat empirical design. The design based on the discovered formula is proposed as an improvement as it is both practical and scientific.

The formula gives an exact statement of the relations of the various design factors involved. It is just as true as the equation of the parabola and to question a design based on it is comparable to questioning the use of the parabola formula in the design of the usual catenary.

The simplicity of the discovered formula indicates that the ideal inclined catenary construction with its two parabolas and connecting parallel hangers is a special shape which is closely allied to other geometrical shapes, the cone, the cylinder, and the sphere. And just as these are inherently best suited for certain mechanical purposes, the ideal inclined catenary shape

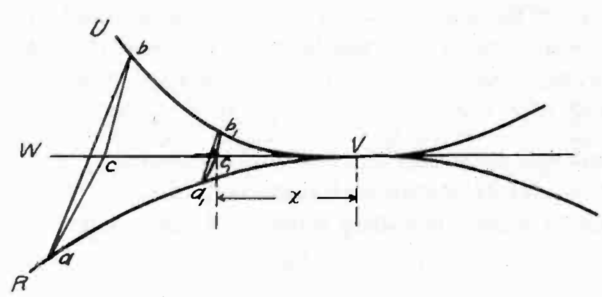

Fig. 9—Sketch Used in Proof that Trace of Elementary Hangers is a Parabola

is especially adapted for railway overhead construction on curves. It fits the track alinement perfectly.

Table of Letters or Symbols

W_c = weight of contact wire in pounds per linear foot,
T_c = tension of contact wire in pounds,
W_m = weight of messenger wire in pounds per linear foot,
T_m = tension of messenger wire in pounds,
a = contact wire in Fig. 1,
b = messenger wire in Fig. 1,
c = inclined hangers in Fig. 1,
d = displacement of messenger,
f = projection of messenger on horizontal plane, Fig. 2,
W_{ch} = unit weight of contact wire with prorated hanger weight in pounds per linear foot,
R = radius of curvature in feet,
h = hanger length,
e = length of shortest hanger at lowest point of sag,
x = horizontal distance of hanger from lowest point of sag,
s = sag of half-span considered,
L = length of span,
W_{mh} = unit weight of messenger wire with prorated hanger weight in pounds per linear foot.

Abridgment of

The Relation Between Frequency and Spark-Over Voltage in a Sphere-Gap Voltmeter

BY L. E. REUKEMA[1]

Associate, A. I. E. E.

Synopsis.—*The standard instrument for measuring crest values of high alternating voltages at 60 cycles is the sphere-gap voltmeter, which measures a voltage by the distance which it will flash between spheres. In much of the high-voltage research, however, very high frequencies are used. For measuring the voltages used in these high-frequency tests, the sphere-gap voltmeter is used, the assumption being made that its calibration at high frequency is but little, if any, different from that at 60 cycles.*

In the endeavor to make the sphere-gap a standard for measuring peak values of voltage at high frequencies, as it is at present a standard at commercial frequencies, experimental data were obtained from which calibration curves for the sphere-gap voltmeter were plotted for frequencies ranging from 28,000 to 425,000 cycles per sec. for standard conditions of temperature and pressure. These curves cover a voltage range from about 10,000 to 50,000 volts, the source of the high-frequency voltage being a Poulsen arc with variable inductance and capacity in its a-c. circuit. The results show no appreciable change in voltage required to flash across a given gap as the frequency increases until a frequency of about 20,000 cycles is reached, then a gradual decrease in required voltage as the frequency increases from 20,000 to 60,000 cycles, after which a single curve holds for all frequencies at least up to 425,000 cycles per sec., the highest frequency tested. The theory shows that this curve should hold up to a frequency of about 6,000,000 cycles for a one-cm. gap, after which a further decrease should be found. At and above 60,000 cycles per sec., the voltage required to flash across a one-in. gap is 13 per cent lower than the voltage required at 60 cycles, provided only the ions occurring naturally in the atmosphere are available to start the ionization which produces the flashover.

In the course of the investigation it was noted that flooding the spheres with ultraviolet light decreased the voltage required to flash across a given gap at high frequency by about 3.5 per cent, whereas no such effect is found at commercial frequencies. Therefore a complete set of calibration curves for the frequency range covered was also obtained for the spheres flooded with ultraviolet light.

The results are explained by showing that at high frequency a space charge of positive ions will accumulate between the spheres, this space charge distorting the potential gradient sufficiently to allow a spark to pass, even though the average gradient between spheres is considerably lower than is necessary at 60 cycles. The space charge depends on the rate at which ions are added to the field by ionization and the rate at which they are lost by diffusion and mutual repulsion, the terminal condition reached when the rate of gain equals the rate of loss determining the voltage at which flash-over will take place at any given frequency.

One of the prime requisites in all high-voltage research is to be able to measure accurately the voltages employed, and, since it is the peak value of the voltage wave which ruptures insulation, it is especially important to be able to determine this peak value. For such measurements at commercial frequencies, that is, 25 to 60 cycles, the sphere-gap voltmeter, which measures a voltage by the distance which it will flash between spheres, is now the standard instrument. For much of the research in high-voltage phenomena, however, very high-frequency power is used. The sphere-gap voltmeter is the accepted means of measuring such voltages, the assumption being made that the calibration of the instrument is little, if any, different at high frequency from that at 60 cycles. To test the correctness of this assumption was the first object of this research.

In the course of taking the experimental data to determine the relation of frequency to spark-over voltage between spheres, an interesting and important fact was noted, namely, that exposing the spheres to the action of ultraviolet light has a very pronounced effect on the voltage necessary to flash across a given gap. At 60 cycles, the action of ultraviolet light on the spheres is merely to increase the accuracy of the sphere-gap as a voltmeter, but the average voltage required to spark across a gap is neither increased nor decreased to a noticeable extent. At high frequencies, however, a pronounced lowering of the voltage required for a given gap manifests itself whenever a source of ultraviolet light plays upon the spheres. The investigation of this phenomenon, discovered many years ago by Hertz, but apparently overlooked by engineers, constituted the second object of our research.

In any investigation of physical phenomena, the value of the experimental data is considerably enhanced if a rational explanation of the results accompanies them. Such an explanation, on the basis of the fundamental physical principles known concerning electrical discharges through gases, together with an attempt to correlate the newly discovered phenomena with already existing knowledge on the subject, is the third object of the research.

Previous Investigations

On June 24, 1914, at the A. I. E. E. convention at Detroit, F. W. Peek, jr., discussed the effect of frequency on spark-over voltage between spheres as one of a number of related investigations carried on, at the General Electric high-tension laboratory, under his direction. He compared a 1000-cycle curve with a 60-cycle curve and found no difference with spark-over voltage plotted as a function of the gap. A 40,000-cycle curve, however, lies below the 60-cycle curve for

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Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Calif., Sept. 13-16, 1927. Complete copies upon request.

its entire length, the percentage differences increasing as the voltage increases, from about 11 per cent at 11,000 volts to 16 per cent at 25,000 volts, high frequency. He attributes the decrease in required voltage at high frequency to rough spots on the spheres, as no special care was taken to polish them.

At this same convention, Professors Harris J. Ryan and J. Cameron Clark of Stanford University reported the results of an investigation which they had conducted on the relation of frequency to spark-over voltage, presenting curves of voltage as a function of spark-over distance at three frequencies, 123,000 cycles, 255,000 cycles, and 612,500 cycles. Ryan and Clark drew a single curve through the mean of all points, compared this curve with a 25-cycle curve located by Fortescue and Chubb, and found their own curve to lie almost uniformly 4500 volts below the 25-cycle curve, at least within the range from 20,000 to 50,000 volts. Ryan and Clark used seven-in. spheres, however, while Chubb and Fortescue used spheres 25, 37.5, and 50 cm. in diameter. To determine whether this difference in voltage might possibly be due to a difference in the size of the spheres used, the writer compared

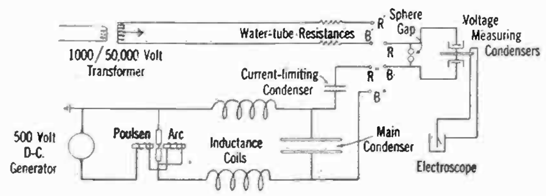

Fig. 1—Diagram of Connections for Calibrating Sphere Gap at High Frequency and High Voltage

the curve of Ryan and Clark, changed to standard conditions of temperature and pressure, with a curve for seven-in. spheres calculated from Peek's formula for spark-over voltage for spheres of any size. In this comparison, the high-frequency curve veers away from the 60-cycle curve more gradually, but at about 50,000 volts the high-frequency curve lies 6500 volts or about 13 per cent below the 60-cycle curve.

Alexanderson also investigated the problem to a slight extent in 1914 with his 100,000-cycle sine-wave alternator, and found that a three-in. gap between five-in. spheres breaks down at about 100,000 volts. He does not definitely state that the high frequency used was 100,000 cycles, nor does he say whether or not one of the spheres was grounded. If it was grounded, as is probable, this shows about a 14 per cent lowering of required voltage at high frequency. Alexanderson used highly polished spheres.

Since the amount of data on the relation of frequency to spark-over voltage by all experimenters combined is rather meager and some of it conflicting, the present investigation was conducted in the hope of clearing up the question, and thus making the sphere-gap a standard means of measuring high-frequency voltages, as it is at present a standard for 60 cycles.

The Present Investigation

The generation of voltages ranging up to 50,000 volts at frequencies of 60 to 500 cycles presented no difficulty, as generators and transformers for these frequencies were available. A diagram of the set-up for the tests is shown in Fig. 1. For the higher frequencies, a two-kw. Poulsen arc, generously loaned to us by the Federal Telegraph Co., was the source of power. For the a-c. circuit of the arc, we constructed a large air condenser and 24 inductance coils, of open design so as to withstand the high voltages induced, and with a minimum ratio of resistance to inductance, so as to obtain a maximum induced voltage. The inductance coils and the condenser are connected in series across the arc, the leading reactance of the condenser neutralizing the lagging reactance of the inductance coils, so that only the high-frequency resistance of the circuit limits the flow of current. The voltage built up across the coils and that across the condenser neutralize each other, so that either one may be over a hundred times as large as the d-c. voltage impressed across the arc. The high voltage between the condenser plates is impressed across the sphere-gap voltmeter. By varying the distance between the condenser plates and the number of inductance coils used, the frequency may be varied over a range from 28,000 cycles to about 450,000 cycles per sec. according to the formula

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where f is frequency in cycles per sec., L is inductance in henrys, and C is capacity in farads.

To measure the voltage impressed between the spheres, three condensers in series to break up the voltage were used, a gold-leaf electroscope reading the voltage drop across the middle condenser. The electroscope reads effective values of voltage, whereas it is peak value which causes a flashover; therefore the wave forms of the low-frequency voltages, over the entire range of voltages used, were photographed with an oscillograph and the oscillograms analyzed mathematically to determine the ratios of effective to maximum voltages for this range. The voltage waves from the Poulsen arc were investigated with a sensitive wavemeter, and all harmonics found to be negligible, so that they may be assumed to be pure sine waves within a very small fraction of one per cent.

Description of Apparatus

The sphere-gap voltmeter was constructed according to A. I. E. E. specifications. The spheres are of brass, 6.25 cm. in diameter and accurately turned. The lower sphere is movable in a vertical direction, and the gap may be readily read to a thousandth of an inch. Neither sphere was grounded.

Since the high-frequency voltage obtainable from a Poulsen arc equals $\frac{E}{R}\sqrt{\frac{L}{C}}$, in which E is the voltage across the a-c. terminals of the arc, R is the resistance of the a-c. circuit, L is the inductance of the coils, and C is the capacity of the condenser, a high ratio of inductance to resistance is necessary in the coils in order to induce the large voltages desired. The resistance of the coils at high frequency is many times that at 60 cycles, due to both skin effect and to eddy-current loss in the copper caused by the magnetic flux of the coil cutting the turns. The coils used were designed to make this high-frequency resistance a minimum, using formulas developed by C. L. Fortescue and published in the Sept., 1923 issue of the *Journal of the British Institution of Electrical Engineers.* Twenty-four coils were constructed, 30 in. in outer diameter and 12 in. in inner diameter, containing eight layers of three turns each, turns being mounted on wooden pegs and spaced one in. apart. The smallest high-frequency resistance for this size of coil is obtained by using No. 9 B & S gage wire.

The condenser plates used measured seven by eight ft. and were constructed of galvanized iron nailed to wooden frames, with quarters of copper float balls soldered to the four corners and with metal connectors soldered to the sides to receive the connections from the inductance coils. To prevent stray electrostatic flux from these condenser plates from spreading out into the voltage measuring apparatus, grounded shields of fine-mesh chicken wire, stretched on pipe frames, were hung on both sides of the condenser.

In parallel with the sphere-gap were three air condensers in series, the middle one of the three having a much larger capacity than that of the two outer ones. These condensers divide the voltage between them in inverse ratio to their capacities, so that the voltage drop across the middle one was about two per cent of the total voltage impressed across the sphere-gap. This voltage drop across the middle condenser was measured by means of a gold-leaf electroscope, connected in parallel with the condenser.

The electroscope consists of a nickeled steel case with glass front and back, down the center of which extends a nickeled brass rod carrying the gold leaf. To prevent possible external flux from penetrating the interior of the electroscope, the glass front and back were threaded both horizontally and vertically with fine wires. The rod bearing the gold leaf is insulated from the case by sulphur. A protractor was arranged to turn on an axis in line with the point of connection of the gold leaf, a line peep-sight directly in front of the protractor and a frame carrying a fine hair about four in. behind the protractor turning with the latter as an integral part. This makes it possible to read the deflections of the gold leaf to the tenth of a degree, which compares favorably with the accuracy of the sphere-gap itself.

Whenever a spark takes place between the spheres, a short circuit is produced across the transformer in the case of the low frequency and across the Poulsen arc in the case of the high frequency. To prevent the burning and pitting of the spheres which would otherwise result from such short circuits, water-tube resistances were placed in both high-tension legs of the transformer circuit, and a one-μ f. condenser successfully limited the flow of current from the high-frequency circuit. The voltage drops in the water-tube resistances and in the current-limiting condenser occurred before the voltage was impressed on the sphere-gap and measuring condensers and therefore were in no sense a source of error in the measurements.

The source of ultraviolet light with which the spheres were flooded was an open arc light, ordinarily used for oscillographic work, which was placed about four ft. from the spheres with the light concentrated on them.

Procedure

As the sphere-gap voltmeter is a standard instrument for the measurement of high voltage at 60 cycles, the electroscope was calibrated by reading its deflections for spark-overs between the spheres for voltages ranging from about 7000 to 55,000 volts effective, the voltage being varied by varying the field of the alternator. Since the object of the research is to compare the high-frequency voltage corresponding to a given gap with that required at 60 cycles, this method eliminated the errors which would have crept in if the electroscope had been calibrated with direct current and the capacities of the condensers measured. The readings of the sphere-gap were reduced to standard conditions, 760-mm. pressure and 25 deg. cent., as adopted by the A. I. E. E., and were also corrected for wave form, since the sphere-gap measures crest values and the electroscope effective values of voltage. Although the generator supplying the 60-cycle power produced a practically pure sine wave, the voltage drops within the transformers due to the harmonics of the exciting currents and the distortion due to the internal capacity of the 50,000-volt transformer produced a slight change in wave form, which necessitated the mathematical analysis of the voltage wave on the high-tension side of the transformer, for the range of voltages used in the test. Oscillograms of these waves at six representative values of voltage were analyzed, and the ratio of maximum to effective value of the actual waves compared to this ratio for a pure sine wave. The corrective value averaged about 0.8 per cent and in no case was larger than 1.8 per cent.

The electroscope and measuring condensers having been calibrated for a given setting of the condensers, high-frequency runs were taken, reading electroscope deflections as a function of distances between spheres for the maximum range of voltages obtainable at any one frequency. Temperatures and barometric pressures were recorded, so that the gap readings might later be reduced to those for standard conditions. The voltages were varied by changing the d-c. voltage impressed on the Poulsen arc, the length of the arc-gap, and the strength of the magnetic deflecting field so as to give steady operation. Frequencies were varied by changing the number of inductance coils used and the distance between the main condenser plates. Frequencies were calculated from the wavelength readings of a wave meter. Runs averaging approximately 100 readings each were taken for frequencies ranging from 28,170 to 425,500 cycles, both with the spheres flooded with ultraviolet light and without. Runs at 133 cycles, 250 cycles, and 500 cycles were also compared with those for 60 cycles. In order to be sure that the particular setting of the measuring condensers was not

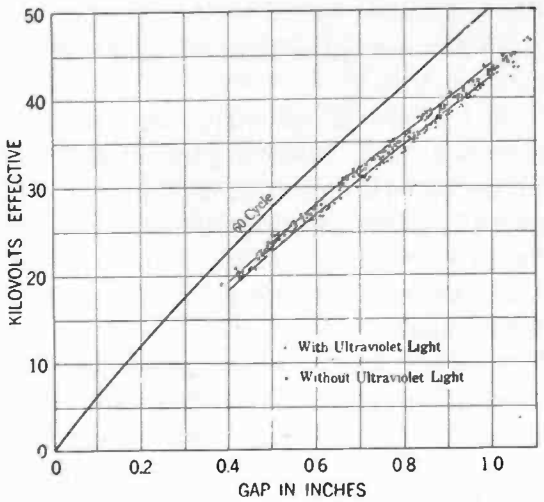

FIG. 2—CALIBRATION OF 6.25-CM. SPHERES AT 95,540 CYCLES

a source of error, runs were taken for several different settings, each setting requiring a separate electroscope calibration. The surfaces of the spheres were kept highly polished at all times, by polishing them with a power buffer at least once and usually several times

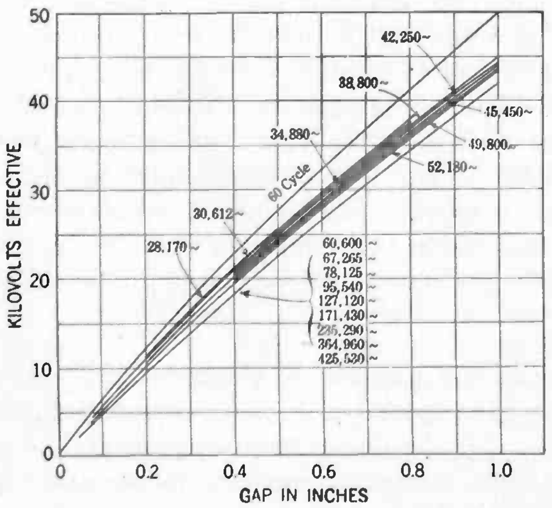

FIG. 3—CALIBRATION OF 6.25-CM. SPHERES AT VARIOUS FREQUENCIES USING ULTRAVIOLET LIGHT

during each run, and by hand with a soft towel after each spark-over.

To obtain a reading, the distance between spheres was made slightly greater than could be flashed across by the voltage impressed, then the spheres were slowly moved together by turning the control wheel until the spark occurred, at the same time keeping the peep-sight of the protractor arrangement trained on the deflected gold leaf, so that the voltage at the instant of flashover could be read accurately. The spheres were always moved together at least a full turn of the control wheel before a flash took place, so as to avoid any error due to lost motion in the control wheel. In case the voltage at the instant of flashover was unsteady, the reading was thrown out. Care was taken to bring the voltage from the Poulsen arc up to the maximum possible with the d-c. voltage impressed before taking a reading, so as to eliminate errors due to surges.

DATA AND CURVES

The publishing of the 50 pages of data secured would serve no useful purpose, since the curves show the results obtained. Moreover, of the many pages of curves plotted, only three are included in this paper. Fig. 2 is included to show approximately the accuracy with

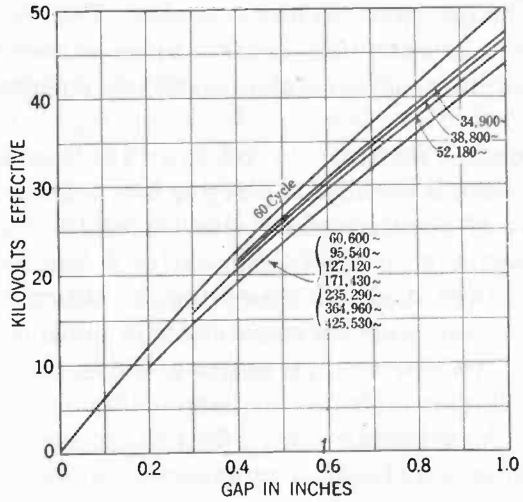

FIG. 4—CALIBRATION OF 6.25-CM. SPHERES WITHOUT ULTRAVIOLET LIGHT

which the points fall on the various curves, and the very evident difference between the voltage necessary to flash across a given gap when the spheres are flooded with ultraviolet light and when they are not. The fact that all points do not fall accurately on the curve when ultraviolet light is flooding the spheres is due to a slight unsteadiness which is inherent in the Poulsen arc, not to any inaccuracy of the sphere-gap itself. Using ultraviolet light, 60-cycle curves always repeat themselves accurately, no point falling more than a quarter per cent off the curve. When ultraviolet light is not used, any point may be as much as two per cent off the curve.

Figs. 3 and 4 show the final results of the test, the one when the spheres are flooded with ultraviolet light, the other when the spheres are not so flooded.

THEORETICAL EXPLANATION OF THE RESULTS

Mechanism of the Spark. Before considering the phenomena of electric discharge through gases, it may be advisable to recall certain fundamental concepts of the constitution of matter. All matter is composed of molecules in continuous motion, the temperature of any substance being merely a function of the energy of motion of its molecules. In a gas, such as our atmosphere, the molecules are relatively far apart, and the continual collisions of molecules with each other and with the walls of the containing vessel give rise to the pressure of the gas. The average distance traveled by a molecule before colliding with another molecule is known as its mean free path. All molecules, in turn, are composed of atoms, different combinations of the 92 kinds of atoms producing the millions of varieties of molecules. The atoms are composed of a central nucleus with a positive electric charge and of particles of negative electricity, called electrons, which travel around the nucleus in precessing elliptic or circular orbits at enormously high speeds, the electrical attraction of the positive nucleus for the negative electrons balancing the centrifugal force produced by these speeds. An atom thus may be compared to a solar system, its volume being mostly empty space. The number of planetary electrons in a neutral atom is always equal to the number of equivalent positive charges of the nucleus.

It is possible for an atom to lose an electron, however, in which case it is called a positive ion, since the loss of a particle of negative electricity leaves the rest of the atom positively charged. Similarly, a free electron is able to attach itself to most atoms. When this happens, the atom with its extra electron is called a negative ion. An ion, whether positive or negative, behaves like an ordinary molecule, as long as it is not in an electric field. As soon as an electric field is produced, however, the ion adds to its haphazard molecular motion a motion in the direction of the field, toward the positive electrode if a negative ion, toward the negative electrode if a positive ion. If this motion takes place in a vacuum, so that the mean free path of the ion is large, a comparatively small voltage drop, about 16 volts for air, is sufficient to give the ion such a high velocity that it is able to knock an electron out of a molecule with which it collides. This potential is known as the ionizing potential of the molecule, that is, the potential necessary to knock out one of its electrons and thus make an ion of it. As the pressure of the gas increases, however, the mean free path decreases until at atmospheric pressure the air molecule has a mean free path of only about 0.000004 in. In such a short distance it does not have the chance to acquire the ionizing speed except at very high potential gradients.

Whenever a molecule is ionized, the electron which is knocked out of it also feels the force of any electric field in which it finds itself. As an electron weighs only about one sixty-thousandth part as much as an oxygen molecule, however, and since the acceleration which an object undergoes in a given field is inversely proportional to the square root of its mass, its acceleration is evidently about 240 times that of an ionized oxygen molecule. Moreover, due to its increased speed and its much smaller size, its mean free path is four times the square root of two or 5.66 times that of the molecule. The electron, therefore, will attain a velocity many hundreds of times that attained by an ion in the same field. Moreover, because of its smaller weight, as compared with that of a molecule, the electron cannot lose more than a small fraction of its energy in an ordinary collision with a molecule. Thus it gradually accumulates velocity until the average amount it loses per collision equals that gained between collisions, the terminal velocity being a function of $\frac{E}{d}$, where E is potential gradient and d is density of the air. If the amount of energy represented by this terminal velocity is as great or greater than the energy necessary to ionize a molecule, such an ionization may take place, the probability of the ionization increasing rapidly with increase in velocity, up to velocities far beyond any which would be given the electron in air by an electric field.

Now let us consider the mechanism of the electric spark between two electrodes with a potential gradient between them. Even though this potential gradient is far greater than that necessary to ionize the air molecules, no spark will take place unless there are either ions or electrons present to start the ionization. A few ions per cubic centimeter are practically always present in the air, however, and new ones are being formed, mainly by the action of the penetrating radiation recently investigated by Millikan and by radioactivity, at the rate of about 12 per sec. per cu. cm. The electron starts to ionize at a considerably smaller potential gradient than does the ion, and even though it ionizes only once for every thousand collisions, an electron would increase to approximately 485,000,000 in moving one cm. For instance, the mean free path of the electron in air at atmospheric pressure is about 0.00005 cm. If it ionizes once in a thousand collisions, it would ionize about 20 times per cm. The rate of increase in the number of electrons, due to ionization by electrons alone, is given by the equation

$$n = n_0 \, e^{ax}$$

where n is the number of electrons after the initial electrons have moved a distance x in the direction of the force, n_0 is the number of electrons at $x = 0$, a is the number of ionizations per centimeter, and e is equal to 2.71828, the base of the Napierian logarithm. Since in our assumption a equals twenty, n equals one, and x equals one,

$$n = e^{20} = 485{,}122{,}000.$$

However, one coulomb of electricity equals 6,280,000,000,000,000,000 electrons, so that this enormous number of electrons would have to be formed per second to have just one ampere of current pass. Moreover, as fast as these electrons are produced by ionization, they are swept into the positive electrode, leaving only the small number spontaneously formed by radiation or by radioactivity to carry on the work. Evidently, therefore, ionization by electrons alone will not produce a spark.

For each electron set free by collision, however, there is also produced a positive ion, which is attracted in the opposite direction from that taken by the electrons. If the potential gradient is sufficient to allow positive ions to ionize air molecules by collision, or to knock electrons out of the negative sphere, the number of electrons produced, immediately increases enormously. Suppose that only one in a thousand of the positive ions produced were able to ionize and that this ionization took place close to the negative electrode, where the potential gradient would be greatest. Then one electron, with the help of the electrons which it sets free by collision, produces 485,000,000 positive ions while moving one cm. Of these positive ions, 485,000, each ionizing once, then produce 485,000 new electrons, which, starting close to the negative electrode, each produce 485,000,000 positive ions in moving one cm., or a total of 235,000,000,000,000. One one-thousandths of these, or 235,000,000,000, produce 235,000,000,000 more electrons close to the negative electrode, which in turn produce 485,000,000 times 235,000,000,000 electrons, and so on, all of this happening in a very small fraction of a second. The process is thus cumulative, the number of ions and electrons increasing at an enormous rate, and resulting in a flashover between the electrodes. Note that ionization by both electrons and positive ions is essential, and that, since the electron ionizes at a lower potential gradient than does the positive ion, the probability of ionization by the latter is the factor which determines the potential gradient necessary to produce a spark between the electrodes. This potential gradient has been found to be 30,000 volts per cm. under standard conditions of temperature and pressure.

The reason for the increased accuracy of the sphere-gap at low frequencies when ultraviolet light shines on the spheres is now easily understood. The action of the ultraviolet light is to liberate electrons from the spheres, a phenomenon which has been named the photoelectric effect. Thus, when the spheres are flooded with ultraviolet light, there is always a large number of electrons in the space between the spheres to start the ionization, and the instant the potential gradient reaches a value of 30,000 volts per cm., a spark takes place. When, on the other hand, the small number of ions found naturally in the air must be depended upon to start the ionization, there may be no ions available at the instant the potential gradient reaches the required value. This is especially true in the sphere-gap voltmeter, in which the potential gradient gradually increases as the spheres are moved together. The gradient, before it has reached the value required for ionization by collision, simply sweeps into the spheres whatever ions are present, so that when the potential gradient does reach 30,000 volts per cm., the diffusion, into the space between electrodes, of ions from the outer space must be depended upon to start the ionization. This may take an appreciable part of a second or even more, during which time the spheres are being moved closer together, with the result that a higher potential gradient seems to be required to flash across the gap than actually is required. Thus, the determination of a voltage by means of a sphere-gap voltmeter, which is not subject to the action of ultraviolet light, may be one or two per cent in error.

Effect of High Frequency

To understand the effect of high frequency on the voltage required to spark across a given gap, we must consider such phenomena as the mobility of ions, their diffusion, and the variation of potential gradient by space charge. The effect of the attachment of electrons to molecules and the recombination of electrons with positive ions to form neutral molecules is negligible in the high electric fields used. The mobility of an ion is the velocity with which it moves in an electric field. The mobility constant is the velocity in centimeters per second attained by an ion, at 760-mm. pressure and 0 deg. cent., per volt per centimeter of field acting upon it. This constant for positive ions in air is 1.32; for negative ions, 1.8. In high fields, the mobility is nearly independent of temperature, so that the error would be small if one neglected to correct gas ion mobilities for temperatures above 200 deg. K. The mobility of *electrons* does not vary directly with potential gradient, so that for electrons there is really no such thing as a mobility constant. The mobility is a function of $\frac{E}{p}$, however, where E is potential gradient in volts per cm. and p is pressure. According to a curve for electron mobility in nitrogen in a paper by Compton in the *Physical Review* of 1923, an electron in nitrogen at atmospheric pressure would attain a velocity of 13,800,000 cm. per sec. under the action of a potential gradient of 30,000 volts per cm., or it would be swept across a gap of one cm. in $\frac{1}{13{,}800{,}000}$ sec. For air, instead of nitrogen, the figures would not differ greatly. A positive ion, under the same conditions in air, would attain a velocity of 30,000 times 1.32 or 39,600 cm. per sec. If the field were an alternating one, the velocity would vary as the voltage varied. For a pure sine wave of 30,000 volts per cm. effective value, the distance traveled by an electron in one sec. in the direction of the force would be 12,160,000 cm.; by a positive ion, 35,650 cm. Evidently at 60 cycles both ions and electrons would practically all be swept out of the field every half-cycle, so that until the potential gradient has reached 30,000 volts per cm., there could be no

Abridgment of

Methods Used in Investigating Corona Loss By Means of the Cathode Ray Oscillograph

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Synopsis.—Methods of employing the cathode ray oscillograph for investigation of corona loss are described. By deflecting the ray of cathode particles (electrons) in one direction within the tube by a voltage proportional to the applied voltage, and in a transverse direction by a voltage proportional to the current, a closed figure representative of the loss, is thrown upon the screen. Methods of obtaining photographic records of these figures and of calculating therefrom accurate values of the power expended are given. The instrument used is well adapted for this work. Power measurements of 0.1 watt can be measured with an accuracy of 1 per cent.

From the volt-ampere cyclograms the characteristics of the positive and negative loss on the a-c. wave are readily observed. The instantaneous voltage of which the loss starts and the instantaneous values of the combined corona and capacity currents can be accurately determined.

Measurements of the corona starting point and loss on various conductors check the laws of corona established by Mr. Peek in 1910. The formulas of "critical disruptive gradients" and "visual disruptive gradients" were closely checked. The loss was found to follow a quadratic above the visual critical corona voltage, e_v. For cables and roughened conductors the excess loss below e_v due to surface irregularities approximately follows the probability law. For smooth, polished conductors the loss suddenly jumps from zero to a definite value at e_v and then follows the quadratic.

The practical effect of the condition of the conductor surface is forcibly brought out by the following data measured on a 336,400-cir. mil cable at 63.5 in. spacing to neutral plane:

Voltage between lines (three phase)	Sixty-cycle loss in kw. per mile of conductor		
	Smooth	Rough	Mutilated
258 kv. (eff.)	49	....	....
220 " "	18	29.4	....
205 " "	0	17.0	38.0
180 " "	0	0	....
132 " "	0	0	4.7

INTRODUCTION

THIS paper describes in detail the methods used in an investigation of corona loss with the low-voltage cathode ray oscillograph. The work, which has been under way for several years in the High Voltage Engineering Laboratory at Pittsfield, Mass., is a continuation of the investigation of corona started by Mr. F. W. Peek, Jr. in 1910.[2] It is hoped that this detailed description of the methods employed in using the cathode ray oscillograph and making the laboratory measurements will be of assistance to other investigators. A discussion of the results and the conclusions are given in Mr. Peek's paper, *Law of Corona—IV*.[3]

In studying the corona discharge, it is highly desirable to make use of an instrument having no power-factor limitations. It is also desirable that the instrument be capable of accurate indications when the current and power involved are small and the voltage high. The low-voltage cathode ray oscillograph is such an instrument.

THE CATHODE RAY OSCILLOGRAPH

This instrument depends for its operation upon a jet, or ray, of cathode particles (electrons) moving at high velocity within an evacuated tube and impinging upon a fluorescent screen. The electrons are discharged from an incandescent filament (the hot cathode). Under the action of a strong electric field, the electrons are rapidly accelerated toward the anode. A small hole in the anode permits certain of the electrons to pass along the axis of the tube in a narrow beam. This beam or ray of cathode particles, which subsequently passes between two pairs of metallic plates upon which voltages can be impressed, can be deflected from its normal course by transverse electrostatic or electromagnetic fields, or by a combination of such fields, and thereby made to trace definite figures on the flourescent screen which becomes luminous at the point at which the electrons strike. These figures are representative of the electrical phenomena taking place within the circuit being investigated, and can be accurately interpreted when the various tube and circuit constants are known. The figures are accurately traced irrespective of the frequency of voltage or current producing the deflections of the electron beam, for this beam has practically no mass and hence no natural period, at least within the limit of the higher radio frequencies.[4]

Photographic Records. Although not strongly luminous, the figure traced on the screen of the tube can be photographed. A sharp image can be obtained by using a lens but the length of exposure required is very great (3 min. or longer). Consequently this method is not desirable when a large number of records is to be taken.

1. Both of the General Electric Co., Pittsfield, Mass.

2. F. W. Peek, Jr., *Law of Corona and Dielectric Strength of Air, I*, TRANS. A. I. E. E., Vol. XXX, pp. 1889-1965.

3. F. W. Peek, Jr., *Law of Corona and Dielectric Strength of Air, IV*.

4. For a more detailed discussion of this device, see article by J. B. Johnson, *Bell System Technical Journal*, November, 1922, p. 142.

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 21-24, 1927. Complete copies upon request.

An accurate but somewhat blurred image can be obtained with a comparatively short exposure by operating the tube in a darkened room or box and placing the emulsion side of a photographic film directly in contact with the end of the tube. The exposure required is about $^1/_{10}$ to $\frac{1}{4}$ second for a straight line image, and about $\frac{1}{2}$ second for other figures. The exposures are made by bringing the filament of the tube up to the proper temperature and then closing the anode circuit for the required length of time.

Corona Loss Measurements

Volt—Ampere Cyclograms. The most satisfactory arrangement for studying corona losses by means of the cathode ray tube has been found in this investigation to be that shown diagrammatically in Fig. 2. A

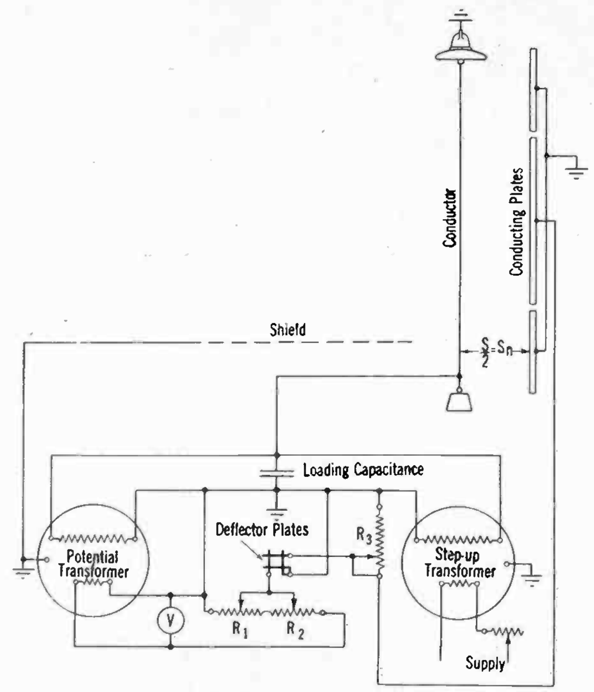


Fig. 2—Diagram of Connections for a Study of Corona by Means of the Cathode Ray Oscillograph

specimen of the conductor to be studied was suspended vertically at a uniform spacing from a broad, vertical metal plate having a length of about 20 ft. This plate was composed of three sections of equal width. The end sections, each five feet in length, were grounded and the middle section, which was insulated from the other two, was grounded through the variable non-inductive resistance, R_3. The function of the end sections was to intercept the corona discharges from the ends of the conductor and leave a uniform section exposed to the active plate.

Although this ground plate, which served as a part of the neutral plane, was 5 ft. wide, it was rather narrow relative to some of the spacings used in the tests. In the near vicinity of the set-up, there were several other grounded objects (principally a metal wall) which were, in effect, extensions of the ground plate. Consequently the active section of the plate was only a part of the practically infinite neutral plane, and therefore intercepted only a fraction of the flux emanating from the conductor. The relative amount of flux intercepted became less as the spacing was increased. The object of this work, however, was to study the critical voltage, the mechanism of the discharge, and the relative rather than the absolute value of the losses. For this purpose, the set-up was found to be entirely satisfactory.

The step-up and potential transformers were identical, and were rated 10-kv-a., 25-cycle, 200/100,000-volt. These transformers were capable of delivering 150,000 volts intermittently without injury and when operated at 60 cycles without high flux density in the core. Voltage control was obtained by means of variable resistances in series with the low-voltage winding of the step-up transformer. Resistances are very flexible and give practically no wave distortion when used in connection with a load of constant impedance, as in these tests. A constant-impedance load, consisting of high-voltage condensers of a total capacity of about 0.00125 μ f., was shunted across the high-voltage winding. This was a load several times as great as that imposed by the exciting kv-a. of the transformers plus the maximum corona loss obtained. The function of this capacitance was to smooth out the voltage wave impressed on the conductor. It accomplished this by supplying the magnetizing current of the transformers and by providing a heavy sinusoidal current to minimize the disturbing influence of the non-sinusoidal corona currents.

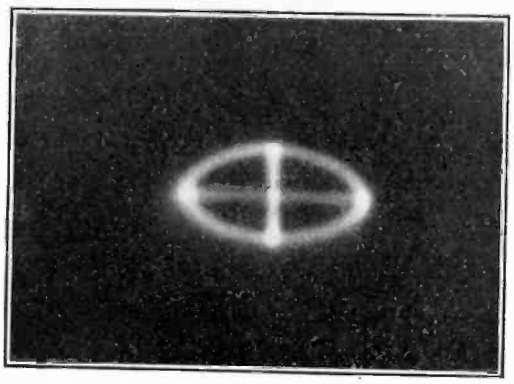
A resistance potentiometer consisting of two non-inductive variable resistances, R_1 and R_2, was shunted across the low-voltage winding of the potential transformer and provided a means of obtaining a voltage of the desired value across the deflector plates of the cathode ray tube. The voltage thus obtained was for any particular setting of R_1 and R_2 proportional to and in phase with the voltage impressed on the corona conductor.[5]

The voltage drop across R_3 was proportional to and in phase with the current flowing to ground from the middle section of the test conductor and was impressed across the remaining pair of deflector plates.

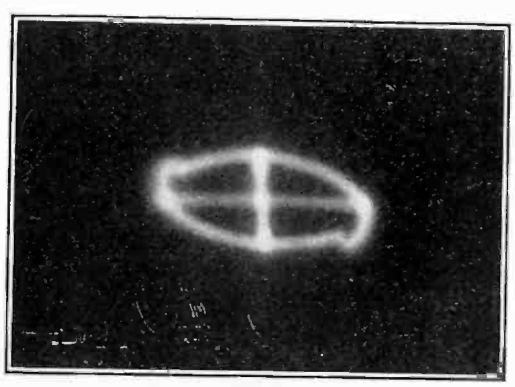
Since the corona phenomena are re-occurring, the figures traced on the screen of the oscillograph tube under the above conditions are stationary and are accurately indicative of the instantaneous relationships between voltage and current. When no corona exists, both the current and voltage waves are sinusoidal and 90 degrees out of phase as dry air is practically a perfect dielectric. The figure traced on the screen is then a pure ellipse. With the connections as shown in Fig. 2, the abscissas of the ellipse are proportional to voltage and the ordinates proportional to current. The cyclo-

5. The phase angle and ratio errors of a high-voltage transformer when operating at low core densities on no load as a step down transformer are very slight and, for this investigation, can be neglected.

gram in Fig. 3A illustrates this condition. The individual axes were obtained by grounding one pair of deflector plates at a time and thus obtaining each separate deflection independent of the other. When corona is present on the test conductor, the voltage remains sinusoidal but the current wave is badly distorted. An individual discharge takes place during each half-cycle of voltage, near the crest of the wave if the impressed voltage is only a few per cent above the critical disruptive value. These discharges appeared on the screen of the tube as an irregular "hump" on each half of the figure. The circuit employed was such



A



B

Fig. 3—Volt-Ampere Cyclograms

A—Below corona starting voltage
B—Just above corona starting voltage
Conductor; No. 00, polished
Spacing; 63.5 in. to neutral
Voltage; 91.0 kv. (eff.) to neutral

that the lower right hand hump represented the discharge during the time that the conductor was negative. The upper left hand hump represented the positive discharge. The cyclogram in Fig. 3B illustrates this condition for a voltage slightly in excess of the visual critical value.

As noted above, a permanent record of the figure traced by the electrons on the screen of the tube was most easily obtained by placing a "super speed" photographic film in contact with the end of the tube. The film was first placed in position in the dark box containing the tube. The tube was then moved ahead by means of an adjusting screw and forced into contact with the film. The filament of the tube was heated to the proper temperature, the required current having been determined previously by means of the filament ammeter and visual inspection of the figure on the screen. The desired voltage was then impressed on the test wire. One pair of deflector plates was grounded

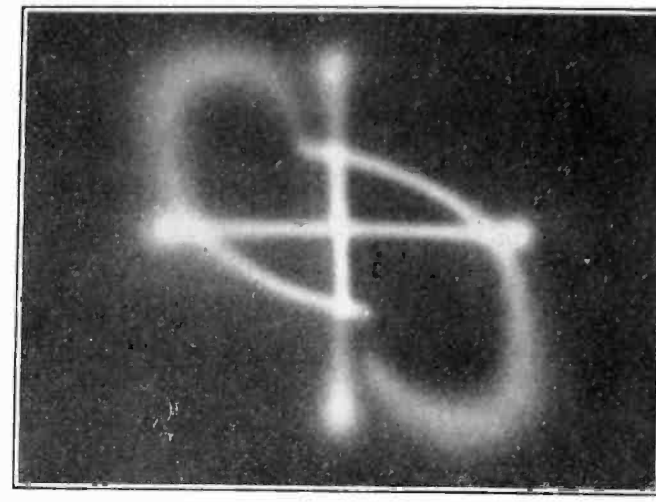


Fig. 4—Volt-Ampere Cyclogram of Heavy Corona

Conductor; No. 00 polished conductor
Spacing; 21.5 in. to neutral
Voltage; 150 kv. (eff.) to neutral

and the anode circuit closed for approximately ¼ second. The first pair of plates was then connected in circuit and the other pair grounded and another ¼-sec. exposure made. Both pairs of plates were then connected in circuit and an exposure of about ½ sec. was made. In this way a record of the figure

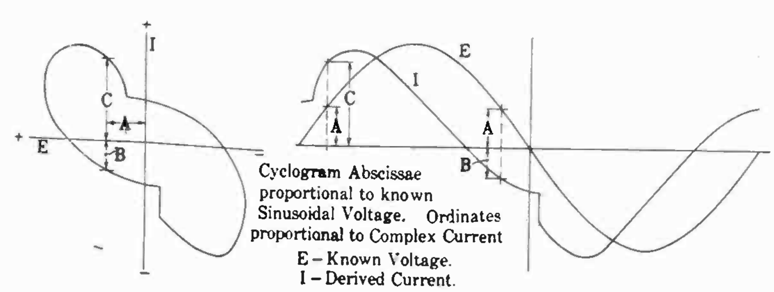


Fig. 5—Graphical Analysis of the Volt-Ampere Cyclogram Shown in Fig. 4

Cyclogram abscissas proportional to known sinusoidal voltage. Ordinates proportional to complex current
E—Known voltage
I—Derived current

and both axes was obtained. The film was developed in the usual manner.

In order that the voltage drop across R_3 be proportional to and in phase with the current flowing to ground from the middle section of the ground plate, it was essential that there be relatively no capacitance or inductance in this part of the circuit. Since the ground capacity of the active section of the ground plate was approximately $4.9 \times 10^{-4} \mu$ f. and was, in effect, shunted across R_3, the value of this resistance, which was non-inductive, was kept less than 100,000 ohms. Consequently the maximum phase-angle error introduced was less than one degree.

A grounded network was placed above the bushings of the transformers to shield out stray fields which otherwise would have reached the effective section of the ground plate.

Most of the work was done at 60 cycles but some measurements were made at 420 cycles. Practically the same test circuit was used in both cases. At normal frequency, even with the loading capacitance removed, the system drew a leading current, but at 420 cycles the impedance of the step-up transformer was so increased and the impedance of the high-side load so decreased that the system drew a lagging current. It was necessary, then, in order to reduce the current drawn from the supply lines to a minimum, to remove the extra capacitance from the high side and shunt a large capacitance across the low side of the step-up transformer.

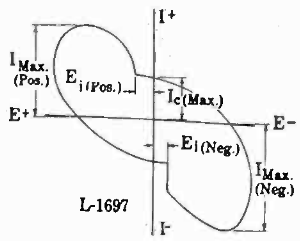


Fig. 6—Corona Discharge Characteristics as Indicated by the Volt-Ampere Cyclogram

E_i Proportional to instantaneous disruptive voltage
I_{max} Proportional to maximum current
$I_{c(max)}$ Approximately proportional to maximum conductor charging current

The sources of power for all of the tests, both 60 and 420 cycles, were sine-wave alternators of large capacity.

Analysis of Cyclograms. Since the abscissas of the cyclograms are proportional to instantaneous voltage, and the ordinates proportional to instantaneous current, if the wave shape of one of the two quantities is known the other can be plotted with time as abscissa and the unknown quantity as ordinate. Fig. 5 illustrates a case in which the horizontal deflection was produced by a known sinusoidal voltage (a voltage proportional to and in phase with the voltage of the test conductor) and hence the current wave, in both magnitude and phase, was readily derived, as shown, from the cyclogram. The original cyclogram from which Fig. 5 was taken is given in Fig. 4.

As well as giving an indication of the wave form of the current in the corona discharge, the cyclograms also provide an accurate means of determining the instantaneous voltages, positive and negative, at which corona forms on the conductor. In Fig. 6, E_i (pos.) and E_i (neg.) represent these voltages.

Since the discharges fade out very gradually, the cyclograms give no definite indications of the exact stopping points. It is evident, however, that the discharges do not persist far beyond the crests of the voltage waves. As brought out later, the stroboscope verified this point.

The maximum charging current of the conductor due merely to the normal conductor capacitance and the maximum *rate of change* of voltage for that particular max'mum voltage is represented (approximately) by I_c (max).

The maximum currents occurring during the discharge are represented by I_{max} (pos.) and I_{max} (neg.).

The rotation of the cathode beam in generating this general type of cyclogram is, as viewed normally, counter clockwise.

Stroboscopic Observations

In order to obtain an approximate check on some of the discharge characteristics disclosed by the cathode ray tube, a stroboscope, or synchronous shutter, was used to permit visual inspection, in a darkened room, of the corona discharge from a polished conductor at any point on the voltage wave. These observations checked the instantaneous disruptive voltages very closely, and indicated definitely that the discharges terminate shortly after the passing of the voltage crests. The corona "sparks" are most intense when they first appear. The illumination then gradually fades out and disappears at a point 10 to 25 deg. beyond the voltage crest.

Power Calculations

When taken by means of the circuit shown in Fig. 2, the cyclograms obtained are volt-ampere curves, the horizontal deflections being practically proportional to and in phase with the sinusoidal line voltage to ground and the vertical deflections practically proportional to and in phase with the complex current flowing between the conductor and ground plate. The average power represented by the cyclogram can then be calculated by either a polar coordinate or rectangular coordinate method as described in detail in the unabridged paper.

Volt-Coulomb Cyclograms. The corona phenomena can be studied from a somewhat different angle if the resistance, R_3, in Fig. 2 is replaced by a capacitance C_3, or by a parallel combination of capacitance and high resistance C_3'. The ordinates of the cyclograms obtained are then proportional to the instantaneous charges induced on the ground plate by the voltage on the conductor.

If pure capacitance is used, the figure will drift over the screen of the tube due to the accumulation of a negative charge on the deflector plate connected to C_3. Since in the case of 60-cycle corona on conductors at relatively close spacings, the positive and negative discharges are of unequal magnitudes, C_3 will accumulate a positive or an additional negative charge which will cause further drifting of the figure. In the case of a small conductor (0.015-in. diam.) at a fairly close spacing (7.5 in. to neutral) it was found that at about 15.0 kv. to neutral the positive excess was just sufficient to compensate for the negative charge acquired from the electron stream within the tube. Consequently the figure would remain stationary near the center of the screen and could be photographed when the line and anode voltages were properly manipulated.

When a high resistance is shunted across C_3 to provide a leakage path for the excess positive or negative component, the figure remains stationary at all voltages and can be photographed in the usual manner.

This type of cyclogram has been employed in other corona investigations, notably those of Dr. Ryan, and provides a convenient means of studying the phenomena from the standpoint of the charge and discharge of "space condensers," but is not so convenient as the first type for power calculation purposes.[6]

Power Loss Data

By means of the first method described above (*i. e.* the volt-ampere cyclograms), loss measurements were made on several solid conductors of various sizes under different conditions of spacing and surface regularity, and also on a large, concentric-strand cable. Typical data are given in Tables I and II and on the accompanying curves.

TABLE I

Conductor:—0.365 in. diam., polished.
Spacing:—63.5 in. to neutral.
Length:—10.0 ft.
Temp.: = 20 deg. cent. Bar. 28.77 in. hg. δ = 0.977
Tube anode potential = 290.0 volts.
E_c = 87.0 kv. eff.

Kv. (eff.) to neutral	R_3 ohms	Power loss (watts)	
		Meas.	Calc.*
87.0	11,067	3.51	2.65
91.0	11,067	7.45	7.22
100.0	11,067	11.8	12.6
115.0	11,067	25.3	25.1
130.0	11,067	43.2	41.8
149.5	11,067	69.7	70.0

*Values calculated by means of Peek's formula (large wires) multiplied by 0.374 (m_o = 1.00)

TABLE II

Conductor 0.365 in. diam., polished.
Spacing:—21.5 in. to neutral.
Length:—10.0 ft.
Temp. = 18 deg. cent. Bar. = 28.47 in. hg., δ = 0.99
Tube anode potential = 290.0 volts.
E_c: Increasing voltage = 77.0 kv. (eff.); Decreasing voltage = 75.0 kv. (eff.).

Kv. (eff.) to neutral	R_3 (Ohms)	Power loss (watts)	
		Meas.	Calc.*
75.0	5040	8.57	15.1
85.0	5040	35.4	31.5
90.0	5040	42.3	42.0
100.0	5040	70.3	67.5
115.0	5040	118.0	117.
130.0	5040	177.	180.
150.0	5040	283.	285.

*Values calculated by means of Peek's formula (large wires) multiplied by 0.73. (m_d = 1.00)

Fig. 10 gives the 60-cycle loss characteristic of a very small, smooth wire (0.015 in. in diameter) at a rather close spacing (7.5 in. to neutral), and at voltages up to the arc-over value. It will be noted that the curve of square root of power against line voltage is very nearly a straight line for a considerable distance above the point marked e_v indicating that in this region the loss followed a quadratic law quite closely. Near the upper end this curve turns up rapidly, indicating that the loss increased at a higher rate just preceding arc-over. Dirt and oxide on this conductor had practically no effect on the loss above e_v. The effective diameter of the conductor was probably sufficiently increased by the foreign matter to compensate for the irregular surface.

Figs. 11 and 12 give the 60-cycle loss characteristics of a large, solid conductor (0.365 in. diameter), both polished and rough, at two spacings (63.5 in. and 21.5 in. to neutral). The curve for the roughened conductor in Fig. 11 was plotted from the data given in Table I, and the curve for the polished conductor in Fig. 12 was plotted from the data given in Table II. No loss whatsoever could be detected from the polished conductor until the visual critical voltage was reached. At this point it suddenly jumped to a definite value and then, with further increase of voltage, followed a quadratic law very closely. It will be noted that for this conductor at the closer spacing two critical voltages are indicated, one for increasing voltage and a different one for decreasing voltage. This characteristic seemed quite definite in the case of large polished conductors at small spacings, and was probably an effect of the space charge created by the uniform corona envelope. The roughened conductor gave a loss at much lower voltages than the polished, and a greater

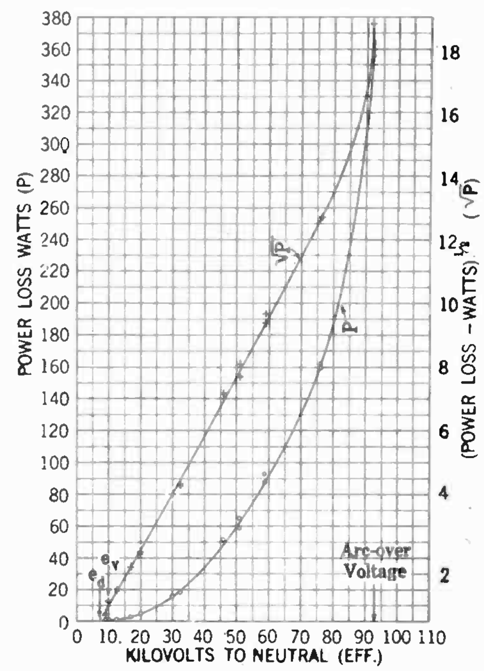


FIG. 10—OBSERVED CORONA LOSS, MEASURED BY MEANS OF THE CATHODE RAY OSCILLOGRAPH

Conductor: 0.015 in. diameter smooth
Spacing: 7.5 in. to neutral
Length: 10.0 ft.
Frequency—60 cycles

6. Ryan and Henline, *The Hysteresis Character of Corona Formation*, A. I. E. E. TRANSACTIONS, Vol. XLIII, 1924, p. 1118.

loss at the higher voltages. In this case, the loss apparently followed no definite law and was very sensitive to accidental surface conditions until well above the starting voltage, when the curve became a quadratic. The excess loss above the quadratic due to surface irregularities gave a typical probability curve.

Loss measurements were made on a 336,400-cir. mil

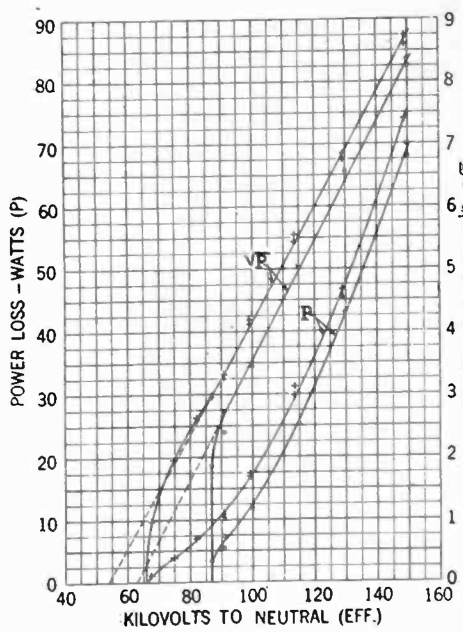


Fig. 11—Observed Corona Loss, Measured by Means of the Cathode Ray Oscillograph

Conductor: 0.365. in. diameter
° smooth surface
+ rough surface
Spacing to neutral: 63.5 in.
Length: 10.0 ft.
Frequency—60 cycles

A. C. S. R. (aluminum conductor steel reinforced) cable with the surface in three different conditions, namely, smooth, rough and mutilated. A smooth, clean cable spaced 63.5 in. to neutral gave no loss below 119.0 kv. to neutral and closely followed the quadratic, for $m_0 = 0.85$, above 125 kv. This value of m_0 was about the average obtained with this conductor at the 21.5-in. and 63.5-in. spacings. In the case of the roughened conductor, the outside strands were scratched as if the cable had been dragged over rough ground, and were covered with spots of dirt and oxide. The loss started at a lower voltage (89 per cent of the former starting value) and was higher over the entire range. The outside strands of the mutilated conductor were in a condition such as would be produced by dragging the cable over hard sharp rocks. The loss started at a very low voltage, (53 per cent of the starting value for the smooth conductor), and was of greater magnitude than in the other two cases.

It was found that the curve obtained by subtracting the quadratic from the loss curve of the mutilated conductor was a typical probability curve. Extrapolation of the curves for the three conditions beyond 150 kv., (up to which voltage the measurements were taken), showed them to come approximately together at 185 kv.

The loss from the smooth cable had much the same characteristics as that from the roughened solid conductor. The surface irregularities in the former case due to stranding and in the latter case due to burrs and scratches caused the loss to begin below the "visual critical voltage," e_v, (for a smooth conductor of the same diameter), but not so low as the critical disruptive voltage, e_0. The quadratic seemed to apply when the true critical voltage, e_v, was approached. As was mentioned in connection with the solid conductors, the loss from the cables at voltages below e_v was very sensitive to changes in surface condition. When the strands were badly scratched, the loss started at a relatively low voltage, far below the value of e_0 for the smooth cable, and was of considerable magnitude at voltages too low to cause any discharge from the undamaged conductor.

It is of interest to study the data obtained with the above three specimens of cable and the following conclusions are of particular interest:

1. At e_v, corresponding to a three-phase line voltage of 258,000 volts, the loss from the smooth cable was 49 kw. per mile of conductor.

2. At 220,000 volts, three-phase, the loss from the smooth cable was 18.0 kw. per mile and from the rough cable was 29.4 kw. per mile.

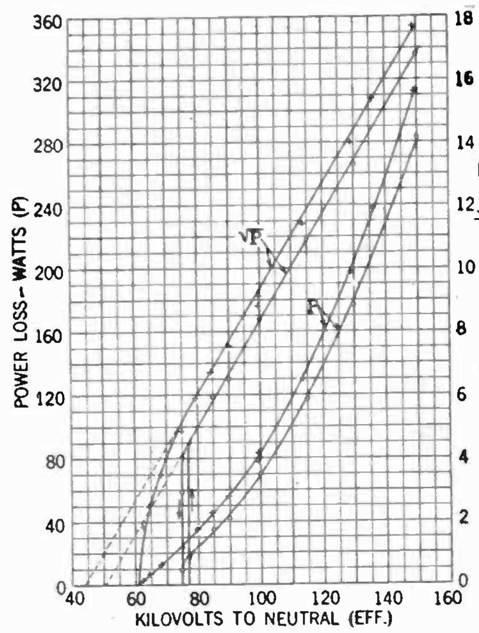


Fig. 12—Observed Corona Loss, Measured by Means of the Cathode Ray Oscillograph

Conductor: 0.365 in. diameter
° smooth surface
+ rough surface
Spacing to neutral: 21.5 in.
Length: 10.0 ft.
Frequency—60 cycles

3. At 205,000 volts, three-phase, there was no loss from the smooth cable; 17.0 kw. per mile loss from the rough cable, and 38.0 kw. per mile loss from the mutilated cable.

4. At 132,000 volts, three-phase, the loss from the mutilated cable was 4.7 kw. per mile of conductor.

5. At sea level, and in fair weather, the smooth cable would operate at 205,000 volts, and the rough cable at 180,000 volts, three-phase, without corona loss. Corona would still be present on the mutilated cable at 130,000 volts, three-phase.

From the above data, it is evident that a great deal of care should be exercised in stringing the lines in order to keep them as free as possible from burrs and scratches. It is also evident that small changes in the surface condition of the conductor produce large changes in the magnitude of the loss near the critical voltage. The

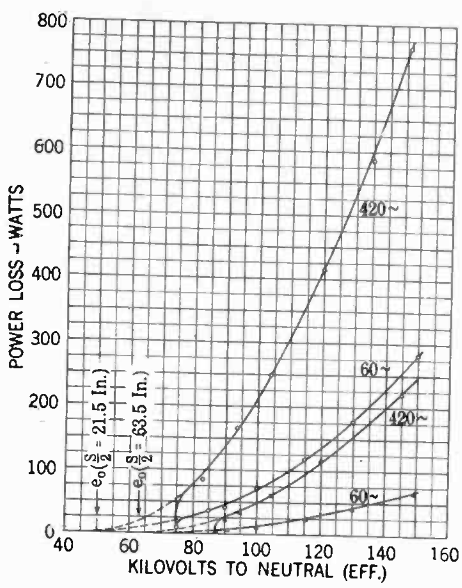


FIG. 13—OBSERVED CORONA LOSS—MEASURED BY MEANS OF THE CATHODE RAY OSCILLOGRAPH

Comparison of losses at 420 cycles and 60 cycles
Conductor: 0.365 in. diam., polished surface

Spacing to neutral: $\left(\frac{S}{2}\right)$; ° = 21.5 in.

△ = 63.5 in.

Length: 10.0 ft.

deviation of the loss curve from a quadratic below e_v seems to follow the probability law and, since the loss below e_v is determined by the size, projection, and number of irregular "spots" on the conductor, it is reasonable that this law *should* apply, at least approximately.

It seems that the best general practise is not to attempt to design the line for a given amount of corona loss, but to so choose the conductor and spacing that the dielectric strength of air (*i. e.*, 30 kv. per cm. max. under standard atmospheric conditions) multiplied by the irregularity factor of that conductor is not exceeded at the conductor surface for the highest operating voltages. Recent developments in the manufacture of cables having large diameters relative to their effective cross sectional areas make it economically possible to design and construct corona-free lines.

The irregularity factor is determined by actual measurement on a specimen of the given conductor or a similar conductor which has been installed and well weathered under the particular conditions involved.

Radio interference, and interference with successful carrier-current communication on the line itself are gaining importance as factors making the elimination of corona an important matter.

Loss at Higher Frequency. Fig. 13 gives the loss characteristics of a large solid conductor, polished, at 420 cycles in comparison with the same at 60 cycles. The ratio of losses at the closer spacing was about 3 and at the greater spacing was about 3.5. The conduction component of the loss was apparently considerably greater at the small than at the large spacing and probably accounted for the difference in ratios. These curves are quadratics with the same critical voltages as the 60-cycle curves on the same conductor.

COMPARISON WITH RESULTS OF PREVIOUS INVESTIGATIONS

The quadratic law, which was established by Mr. Peek in 1910, was closely checked for voltages above the "visual critical" value (e_v). Below this voltage, the deviation from a quadratic of the loss curves for cables and roughened solid conductors was found to follow the probability law closely.

In order to obtain absolute values, it is necessary to correct the loss data obtained in these tests because the ground plate did not intercept all the electrostatic flux emanating from the conductor. The correction varies with the spacing. For any given spacing, however, the percentage of flux intercepted by the plate is approximately constant regardless of the voltage.

The correction is readily obtained by comparing the calculated charging current of the conductor with the measured values. In this manner it was found that at a spacing of 63.5 in. to neutral, about 44 per cent of the total current was measured, and at a spacing of 21.5 in. to neutral, about 78 per cent was measured. The uncorrected measured loss at the greater spacing was about 38 per cent of the value calculated by means of Peek's formula and, at the smaller spacing was about 70 per cent of the calculated value.

The formulas for critical disruptive gradients and particularly the visual critical gradients as determined by Mr. Peek's early work were closely checked.

Over the entire range of conductors tested, a remarkably close agreement exists between the observed and calculated values of e_v. There is also a fairly close agreement between the observed and calculated values of e_d.[7] In the case of the roughened solid conductors the loss actually started at voltages well above the e_d of the same conductor in a polished condition. The same may be said regarding the roughened cable. For the mutilated cable, however, e_v is lower than e_d ($e_d = e_0$ in the case of large conductors such as this). This

7. e_d = Disruptive critical voltage in Peek's formula. e_d practically equals e_0 for conductors of a diameter greater than about 0.15 inches. See "Dielectric Phenomena in High Voltage Engineering," by F. W. Peek, Jr., pp. 117-152.

condition is largely accounted for by the presence on the cable of numerous sharp projections which produced flux concentrations and consequently, local discharges at relatively low voltages.

Characteristics of the Corona Discharge

Typical cyclograms showing the discharge characteristics under different conditions are given in Figs. 3B, 4 and 14. It will be noted that for polished conductors (Figs. 4 and 14 left side) the individual discharges, particularly the negative, form very suddenly, and the current waves contain abrupt distortions. In the case of roughened conductors (Fig. 14 right side) and cables the individual discharges form much more gradually and the current wave distortions are much less abrupt.

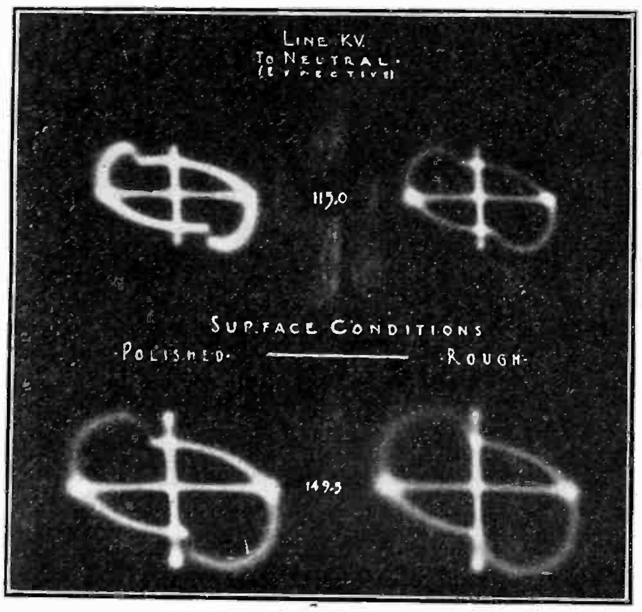


Fig. 14—Comparative Cyclograms Showing the Influence of Conductor Surface Condition Upon Corona Discharge Characteristics.

Conductor: solid, 0.365 in. diam.
Spacing to neutral: 63.5 in.

Fig. 14 illustrates the influence of surface conditions upon the magnitude and character of the discharge.

The decrease of instantaneous disruptive voltage with increasing line voltage is shown in Fig. 14.

Summary

The low-voltage cathode ray oscillograph is well adapted to investigations of phenomena involving small currents of complex wave shape. This instrument was used in a study of the volt—ampere characteristics of the corona discharge. The circuit employed was such that the figures traced on the screen of the tube were volt—ampere cyclograms. These cyclograms were photographed by placing the film directly against the end of the tube and the power expenditure represented was calculated by a method which was in effect the same as that of transcribing the polar figures to rectangular coordinates and integrating the power wave in the usual manner. The results were converted to watts by means of the tube calibration data which were obtained by impressing definite voltages across the deflector plates and measuring the resulting deflections.

The cyclograms give accurate indications of the structural nature and characteristics of the corona discharge.

Some of these characteristics were checked visually by means of the stroboscope.

The following conclusions were drawn regarding the power loss and starting voltage:

1. Above the "visual critical voltage," e_v, as given in Mr. Peek's early work, the loss-voltage relation is a quadratic.

2. For polished solid conductors the loss suddenly jumps from zero to a definite value at e_v and then follows a quadratic.

3. For cables and roughened solid conductors the excess loss above or below that given by the quadratic law approximately follows the probability law below e_v. This excess loss may be either positive or negative, or both.

4. The critical disruptive gradients and particularly the visual critical gradients as determined in Mr. Peek's early work were closely checked.

5. The loss near the starting voltage is greatly affected by the regularity and condition of the conductor surface.

The characteristics of the discharge are briefly as follows:

1. For polished solid conductors the individual discharges, particularly the negative, start suddenly and are accompanied by heavy rushes of current.

2. For roughened solid conductors or cables the individual discharges start gradually and the current waves contain no sharp breaks.

3. The instantaneous disruptive voltages decrease with increasing line voltage.

4. The individual discharges stop near the crests of the voltage waves.

Acknowledgment is made of the assistance of Mr. T. M. Hotchkiss, and others of the staff of the High Voltage Engineering Laboratory.

Many new buildings throughout the country are now equipped with the new type of elevators which are so completely electrified that they operate at high speed and in the service of the tallest buildings practically without the aid of operators. New York has several such buildings and now they are appearing in other parts of the land. Omaha's newest office structure is in the list. When a patron steps on the car at the bottom level, the operator merely presses a button representing the floor at which the passenger wishes to alight. Motors start the car, slow it down, stop it at the designated floor, open and close the doors and carry the car on its way.

Abridgment of

Synchronous Condensers

BY P. L. ALGER[1]

Member, A. I. E. E.

Synopsis.—The paper reviews the general characteristics of large synchronous condensers, with particular reference to the possibilities of greater standardization in condenser specifications. Particular emphasis is placed on the question of the ratio of lagging to leading kv-a. capacity, and it is concluded that about 50 per cent lagging capacity is normal, while any important increase in this ratio requires special design of greater size and cost. Attention is called to the advantage to be gained by the use of reactors in place of such oversized condensers, where extra lagging capacity is needed. Separate sections of the paper are devoted to starting and stability characteristics, and to recent improvements in the design of synchronous condensers. Finally, the use of asynchronous condensers is discussed and found to be undesirable.

* * * * *

I. Object of Paper

The large amounts of leading kv-a. required by modern power systems are most economically provided by means of synchronous condensers, and so the numbers and unit sizes of these machines have steadily increased in recent years. Thus, in 1925 two 40,000-kv-a., and this year, the first of three 50,000-kv-a. condensers were placed in service on the Pacific Coast, while upwards of 35 others of sizes above 1000 kv-a. were built in the United States during 1926. Their continually increasing importance makes it desirable to simplify and standardize specifications for them as much as possible by eliminating unnecessary restrictions on their design.

II. Principal Characteristics of Synchronous Condensers

The outstanding advantage of the synchronous condenser from an operating point of view, as compared with other means of supplying corrective kv-a., is the flexibility of its control. Once the machine is connected to the system, the reactive kv-a. it supplies can be varied continuously over the entire range from 50 per cent or more lagging to full leading kv-a., by simple adjustment of its field current. The adjustment can readily be made fully automatic, and so any desired condition, such as constancy of voltage or of power factor at a given point on the system, can be maintained.[2] This ease of adjustment also enables machines of very large size to be put on or taken off the system without appreciable disturbance. Thus, the economic advantages of large sizes can be fully realized with synchronous condensers.

Also, from the manufacturer's viewpoint, the synchronous condenser has an outstanding advantage over other rotating machines due to the fact that it neither drives nor is driven by any other apparatus. This permits a single, most economical, speed to be used for any given size, which, in turn, greatly helps standardization. Besides, the torque required being merely that to hold the rotor in step, the usual stability limitations of synchronous machines are lifted, and consequently very high current loadings can be employed. All these things contribute to the attainment of low costs. On the other hand, the low initial cost of the condenser itself and the small amount of associated equipment required combine to make the operating cost of the power losses an abnormally high proportion of the whole. On this account, special emphasis is placed on the attainment of low losses in synchronous condensers, and this factor tends to increase the initial cost.

III. Possibilities of Standardization of Condenser Design

Ideal conditions for standardization, combined with progress, exist when specifications are so drawn as to impose the least possible number of fixed requirements, and when contracts are awarded on the basis of the best performance on the non-fixed requirements. In this way, each manufacturer is given maximum freedom for the use of his available developments and for the play of his initiative. When more requirements than those absolutely necessary are laid down, all manufacturers are forced to do some things in the same way, with consequent inconvenience and increased developmental costs for some of them. Synchronous condensers much more nearly approach this ideal condition than most other types of rotating machines, and yet it seems that further progress in this direction can be made.

Aside from the restrictions imposed by the system frequency and by the method of rating employed, there are four variables that the purchaser may specify in describing a synchronous condenser. These are:

1. Leading kv-a. capacity, or rating,
2. Number of poles, or speed,
3. Voltage,
4. Ratio of lagging to leading kv-a. capacity.

The first of these is the fundamental variable that determines the size of the machine, so that the only possibility of standardization here is in the limitation of the number of ratings called for. Present practise

1. A-c. Engineering Dept., General Electric Co., Schenectady, N. Y.

2. Woodruff, "Principles of Electric Power Transmission," p. 153.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Calif., September 13-16, 1927. Complete copies upon request.

in this respect is quite satisfactory, as the list of usual ratings given in the first column of Table I has increments of at least 20 per cent, and intermediate ratings are seldom called for.

It is not desirable for the purchaser to specify the speed, as this limits the manufacturer's possibilities, and usually handicaps one more than another. The natural desire to improve his designs, and the economic urge of competition will cause each manufacturer to select the most economical speed for each machine, and the ultimate user has, therefore, nothing to gain by insisting on any particular value for it. As high-speed machines are lighter and more efficient than low-speed machines up to the points at which mechanical stresses and windage losses become limiting, it follows that synchronous condensers are normally built for high speeds. At the present time the speeds listed in Table I are customary, but the ratings at which the speed is changed vary slightly among different manufacturers. Usually, machines are guaranteed for 25 per cent overspeed.

Sometimes condensers are placed in substations in residential districts where quiet operation is essential, and this has been thought to require machines of lower than standard speeds. However, it is possible to so enclose a high-speed condenser as to make it satisfactorily quiet at less cost, and with better performance than can be obtained by using a speed below standard.

For large sizes, it is often economical to use a completely closed system of ventilation with water coolers, as described in Section VIII. If this is not desired, it is still possible to reduce the noise to a very small amount by using a standard enclosed machine with the addition of an air discharge chimmey on top. Felt-covered baffles can be so placed in this chimmey as to practically eliminate the high pitched part of the noise without impeding the air flow to an important extent.

The voltage situation is not so simple as that of the speed, as there are so many different system voltages employed. However, the recent conferences on the subject, at New York and Niagara Falls, (culminating in the new N. E. L. A. table of preferred standard voltages), give promise of some improvement. Also, as synchronous condensers are frequently provided with their own transformers or are fed from special tertiary transformer windings, it is often possible to choose the voltage that gives the most economical design. If the condenser voltage is too high, excessive insulation costs and extra losses due to the large slots required will result; while if it is too low, excessive costs for the high current-carrying capacity and extra losses due to eddy currents in the massive conductors will arise. Hence, there is a most economical voltage for every rating, values of which are indicated in the third column of Table I.

The remaining variable is the ratio of lagging to leading kv-a. capacity. When a condenser is to be used solely for power-factor correction, to compensate for the lagging kv-a. of an industrial load, the lagging kv-a. capacity is of no direct interest, and so, in these cases, it is rightly left for the manufacturer to settle. As a value of the ratio not far from 0.5 gives the most economical design for leading power-factor operation, this is the value characteristic of most standard condensers. However, when condensers are to be used for voltage regulation, a considerable lagging kv-a. capacity is useful to hold the voltage down at light loads, and so, purchasers frequently specify a value of unity for this ratio. This imposes a considerable handicap on the designer and requires a special machine so that it is desirable to find some other way to obtain the desired results. It is worth while to study this question at some length; so the effects on design of varying this lag/lead ratio will first be described, and then methods of securing the desired operating results with normal condensers will be considered.

TABLE I
MOST ECONOMICAL SPEEDS AND VOLTAGES OF LARGE SYNCHRONOUS CONDENSERS

Kv-a rating	60 cycle, r. p. m.	Voltage
500	1,200	2,400/4,150
750	1,200	2,400/4,150
1,000	1,200	2,400/4,150
1,500	1,200	2,400/4,150
2,000	900	2,400/4,150
3,000	900	2,400/4,150
4,000	900	2,400/4,150
5,000	900	6,900 or 11,500
7,500	900	6,900 or 11,500
10,000	900	6,900 or 11,500
15,000	720 or 900	11,500 or 13,800
20,000	720	11,500 or 13,800
25,000	600 or 720	11,500 or 13,800
30,000	600	13,800
40,000	600	13,800
50,000	600	13,800

IV. Lagging Kv-a. Capacity Secured by Changes in Condenser Design

The line current of a synchronous condenser is always equal to the difference between the voltage induced by its field and the impressed voltage divided by its synchronous reactance and corrected for saturation. Over-excitation of the field produces a leading current, and under-excitation produces a lagging current. The maximum possible lagging current occurs with zero field current, and is therefore equal to the line voltage divided by the synchronous reactance. While stable operation with a small reversed field excitation is possible, the trouble of providing for this reversal and the attendant increased likelihood of the condenser's falling out of synchronism make it inadvisable. For our purposes, therefore, the ratio of maximum lagging to normal leading kv-a. capacity of a synchronous condenser may be taken equal to the reciprocal of the per cent synchronous reactance, or to:

$$\text{Per cent maximum lagging kv-a.} = \frac{100}{X_s} = 100\,Y_s \quad (1)$$

As lagging kv-a. are supplied when the field is under-excited, under this condition the saturation of the magnetic circuit is slight and may be neglected. On the other hand, the leading kv-a. are supplied when the field is over-excited, a condition in which saturation of the magnetic circuit is pronounced.

If the ratio of the actual field excitation to the no-load air-gap excitation is represented by F, the per cent leading kv-a. is determined by the equation:

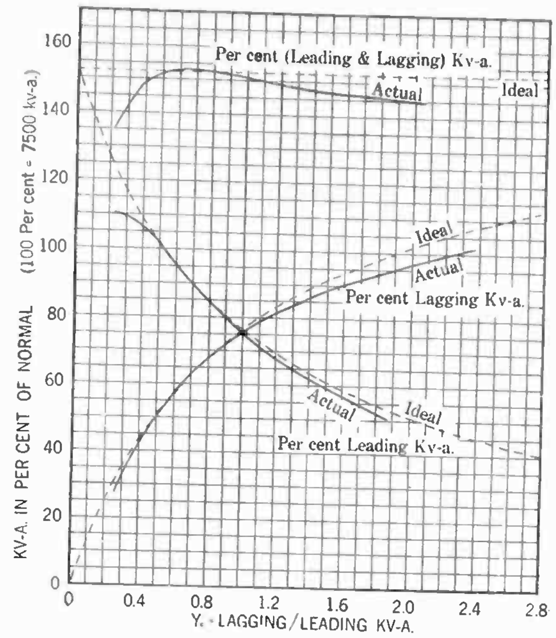


FIG. 1—RELATIVE LEADING AND LAGGING KV-A. CAPACITIES OF A 7500-KV-A., 900-REV. PER MIN. SYNCHRONOUS CONDENSER WITH VARYING AIR-GAP LENGTHS

$$\text{Per cent leading kv-a.} < 100\,(F - 1)\,Y_s \quad (2)$$

Without saturation, the inequality sign becomes an equality sign, so that (2) reduces to (1), if F is made equal to zero. Adding (1) and (2), the sum of the leading and lagging kv-a. is found to be,

$$\text{Per cent (leading + lagging kv-a.)} < 100\,F\,Y_s$$

$$= 100\,\frac{\text{rated field current}}{\text{S. C. field current}} \quad (3)$$

Equation (3) indicates that the sum of the leading and lagging kv-a. capacities of a given machine is nearly independent of the no-load excitation. At full leading kv-a., (2) becomes equal to unity, so that the relation between F and Y_s is found to be,

$$\frac{\text{No-load air-gap field current}}{\text{Full-load field current}} = \frac{1}{F} < \frac{Y_s}{1 + Y_s} \quad (4)$$

Equations (1), (2), and (3) are plotted in Fig. 1 as functions of Y_s. The dotted curves show the ideal conditions in the absence of saturation, while the solid curves show the actual conditions for a particular 7500-kv-a., 900-rev. per. min. condenser with different lengths of air-gap but with constant field excitation.

The figure clearly indicates the sacrifice in leading kv-a. capacity necessary to secure greater lagging kv-a. If instead of merely varying the air-gap, keeping the same stator, the entire design is changed to always keep the current carrying capacity of the stator winding just adequate for the maximum kv-a., slightly greater output can be obtained. For example, at a 100 per cent ratio of lagging to leading kv-a., a complete redesign will enable 83 per cent of normal leading kv-a. to be obtained as compared with only 75 per cent when the air-gap alone is changed. The more extensive changes, however, make the machine more special and require additional developmental charges, so that they are not always of economic advantage.

These results may be summarized by the statement that a synchronous condenser of a given size and cost may be designed to give any one of the four following combinations of leading and lagging kv-a. capacities:

Standard	100% leading, 50% lagging
Semi-standard	90% leading, 65% lagging
Semi-standard	75% leading, 75% lagging
Special	83% leading, 83% lagging

The increase in air-gap length required to give greater lagging kv-a. capacity increases the excitation loss under leading kv-a. operation, so that the efficiency of a condenser is thereby lowered. On the other hand, if the air-gap is made so small that the lagging kv-a.

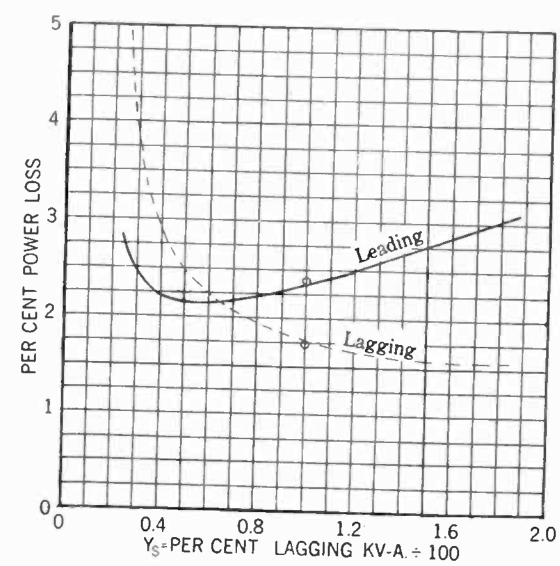


FIG. 2—RELATIVE FULL-LOAD LOSSES OF A 7500-KV-A., 900-REV. PER MIN. SYNCHRONOUS CONDENSER WITH VARYING AIR-GAP LENGTHS

capacity is reduced below about 0.4 of the leading capacity, the tooth frequency iron losses are increased so much that the efficiency is again lowered. Thus, as shown by the curves of Fig. 2, the least losses for leading kv-a. operation with a given size of machine are secured when the ratio of lagging to leading capacity is not far from 0.6.

We, therefore, conclude that it is desirable to keep the value of Y_s between 0.5 and 0.6 for a standard line of synchronous condensers. Wide departures from this range increase both costs and losses and so cannot be considered standard, and keeping closely to it will greatly facilitate standardization and, will tend to further reduce costs and improve performance.

V. Other Methods of Securing Lagging Kv-a. Capacity

There are four principal methods of securing lagging kv-a. capacity without departing from normal condenser designs:

1. By reconnection of the condenser windings,
2. By raising the condenser voltage by means of transformer taps,
3. By use of reactors, and
4. By reduction of the system voltage.

The simplest general method of reconnection is to divide each phase in halves and connect unlike halves in series for lagging power-factor operation. On three phase, this is equivalent to increasing the voltage in the ratio of $2/\sqrt{3}$, and so it raises the lagging capacity to 4/3 of its normal value. However, unless rather complicated internal connections are made, the scheme

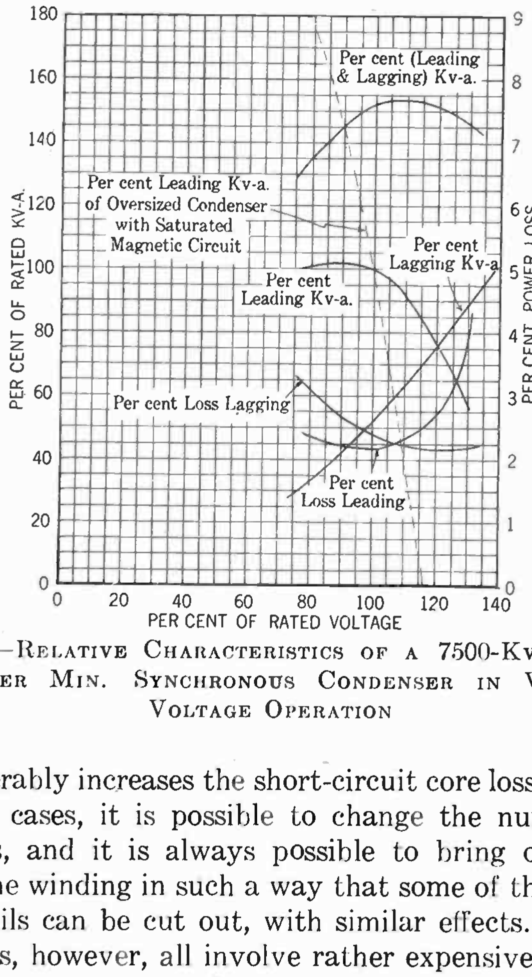


Fig. 3—Relative Characteristics of a 7500-Kv-a., 900-Rev. Per Min. Synchronous Condenser in Variable Voltage Operation

considerably increases the short-circuit core losses.[4] In special cases, it is possible to change the number of circuits, and it is always possible to bring out taps from the winding in such a way that some of the armature coils can be cut out, with similar effects. These schemes, however, all involve rather expensive switching arrangements and they are not conveniently adaptable to automatic operation; also, they all result in increased losses per kv-a. so from this viewpoint they are not attractive. Some of the methods are desirable for use in special cases, such as when a single machine is to be operated at different times on circuits of different frequencies, but they cannot be recommended for standard practise. At best, it is not practicable to double the lagging kv-a. capacity of a condenser by such means, so that they cannot completely solve the problem.

The recent developments in tap changing transformers[5] at first sight give promise of a solution by enabling the voltage to be varied at will over a wide range, without opening the circuit. However, on closer scrutiny, this possibility, too, is seen to be chimerical. In the first place, the tap changing apparatus is quite expensive, and the cost of the condenser is considerably increased by the necessity for insulating it for the highest voltage used. These extra costs alone are about the same as the extra cost of making the original condenser good for full-lagging capacity, and, in the second place, the losses in lagging power-factor operation are considerably increased by this arrangement as compared with the latter scheme.

In Fig. 3 there are shown curves of leading and lagging kv-a. capacity and per cent losses as functions of the impressed voltage, for the same 7500-kv-a., 900-rev. per min., 11,000-volt condenser used in the previous figures. A voltage of about 130 per cent is required to give 90 per cent of rated kv-a. in lagging operation, at which point the losses are 2.2 per cent as compared with only 1.6 per cent for the oversized condenser built with a large enough air-gap to give the same lagging capacity (Fig. 2 at $Y_s = 1.55$). The curves show that no appreciable increase in leading kv-a. capacity can be secured by reducing the voltage, so that there is no incidental gain from this source to offset the disadvantages in lagging operation. We conclude, therefore, that the voltage regulation scheme is not of value for our purpose.

There remains the scheme of supplementing the deficient lagging kv-a. capacity of the standard synchronous condenser by the addition of parallel-connected reactors. As high-voltage air core reactors can now be built at costs per kv-a. which are about half those of synchronous condensers and with total losses of only about 1 per cent, this idea looks promising. The obvious objection to it is that it requires additional apparatus with suitable control and extra floor space. Furthermore, unless the reactors are to be thrown on the line all in one unit, expensive sectionalizing switches are required. Thus, the complete equipment is more expensive than a single oversized condenser designed for full lagging capacity.

In the long run, however, the capital cost of the reactor scheme may prove to be the lower, for lagging kv-a. are principally required when a system is lightly loaded, in order to keep down the no-load voltage. Over a period of time, as the system load increases, the times of light load become shorter, and the minimum

4. Reference No. 6 and Q. Graham, *M. M. F. Wave of Polyphase Windings*, Journal A. I. E. E., February 1927, p. 118.

5. A. Palme, *Application and Design of Load Ratio-Control Equipment*, presented at the Regional Meeting of District No. 1 of the A. I. E. E., Pittsfield, Mass., May 25-28, 1927.

load becomes greater, so that less lagging kv-a. are required, and the demand comes to be for leading kv-a. capacity to hold the voltage up during overloads. Hence in some cases, it should be economical to install reactors alone when a transmission line is first built, later to add standard condensers, and finally to take the reactors away altogether for use at some other place, or for sale.

From the point of view of power losses, too, the reactor scheme may be attractive. Fig. 4 shows the total losses in per cent of kv-a. output for the combination of the standard 7500-kv-a. condenser used in the previous figures with sufficient air-core reactors to give a total of 100 per cent lagging capacity; together with a similar curve for a larger condenser built with a sufficient air-gap to give it 7500 kv-a. capacity on both leading and lagging operation.

All these methods of securing extra lagging capacity involve extra cost and losses, so that it is desirable to avoid the difficulties by merely reducing the system

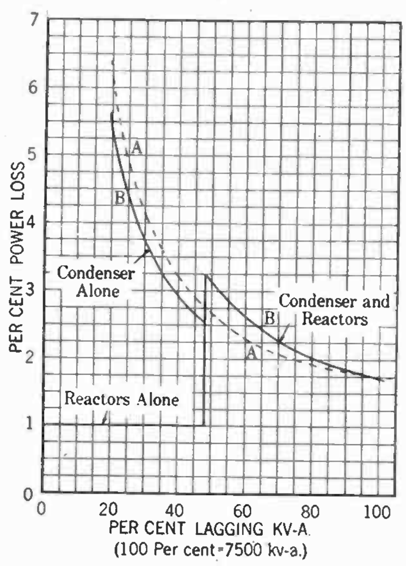


FIG. 4—RELATIVE POWER LOSSES IN LAGGING KV-A. GENERATION

A. Special synchronous condenser with 100 per cent lagging kv-a. capacity

B. Standard synchronous condenser with 52 per cent lagging kv-a. capacity and 48 per cent kv-a. of reactors

voltage. This reduces the leading kv-a. supplied by the transmission line capacity, and increases the lagging kv-a. due to the line reactance, thus greatly decreasing the lagging requirements. The voltage reduction may be made temporarily during a time of light load. In general, a system design that gives permanently large lagging kv-a. requirements is not the most economical.

VI. METHODS OF STARTING SYNCHRONOUS CONDENSERS

It is standard practise to provide synchronous condensers with amortisseur windings and to start them from a low-voltage transformer tap or from an auto-transformer. This method of starting is readily adaptable to automatic operation, and the equipment required costs less than a starting motor with its control and the necessary synchronizing apparatus. Unless a source of low voltage for the starting motor is already available, an extra transformer must be provided for it, and in this case the cost is very much greater; also, automatic operation with a starting motor is more difficult. The only apparent advantage of a starting motor is the possibility of securing a lower reactive component of the initial starting current by its means.

As the starting kv-a. required by a standard condenser is only about 30 per cent of normal, and this can be reduced to about 20 per cent by adding oil pressures starting equipment, it does not seem that the use of a starting motor is ever necessary on this account. However, in rare cases it may be desirable occasionally to use a condenser for line charging or for testing a transmission line, and a starting motor will then be necessary. If a condenser is to be operated on unbalanced voltages or under other conditions where a very low-resistance amortisseur winding is needed, the condenser's starting characteristics will be poor and a starting motor will be desirable.

In order to keep down the induced field voltage, it is customary to short circuit the field through a resistor during the starting period. The condenser will then come up to full speed on the tap voltage, and field is applied before it is thrown over to full voltage. When the change to full voltage is made, the field current being kept constant, the kv-a. drawn from the line will change suddenly by an amount depending on the value of field current used. Let T represent the ratio of tap to line voltage, Y_s the ratio of lagging to leading kv-a. capacity, and E the ratio of the field current during synchronizing to the no-load field current. Then the leading kv-a., drawn from the line on the tap, are represented by:

$$T\,(E - T)\,Y_s$$

and the leading kv-a. on full voltage are:

$$(E - 1)\,Y_s$$

For minimum shock to the system, these two must be equal, whence we find the best value of field current to use on synchronizing is:

$$E = T + 1 \qquad (5)$$

which gives leading kv-a. equal to $T\,Y_s$.

As a standard condenser usually has a no-load field current equal to about one-third of its full-load field current, and as the tap voltage used for starting is usually not over 30 per cent, equation (**5**) shows that the best value of field current for synchronizing is a little less than 40 per cent of its rated value.

In practise it is convenient for the operator to determine the best value of field current by taking two V curves on the condenser, one at full voltage and one on the starting tap, reading the current input on the line side of the compensator. Then, as indicated in Fig. 5, it is a simple matter to prolong the leading branches of the two V curves until they intersect, and this will give the desired field current. The magnetizing kv-a. of the compensator are usually large enough to make the determination by readings on the low side of the compensator considerably in error, as indicated by the dotted line in Fig. 5.

VII. Stability of Synchronous Condensers

There are two aspects of the stability question as it relates to synchronous condensers, the first dealing with the stabilizing effect of a condenser on the system voltage, and the second dealing with the ability of the condenser to stay in synchronism during system disturbances. These will be considered in turn.

A dead system load, made up of lamps, resistors, reactors and so forth, is characterized by a constant ratio between its voltage and current. If the voltage rises or falls, the current does likewise in an equal ratio, without change of power factor. A live load, made up of synchronous and induction motors, is characterized by a constant kilowatt demand, independent of voltage, so that in this case the power component of current rises if the voltage falls, and vice versa. With a dead load, therefore, a fall in voltage results in a decrease in line drop, while with a live load a fall in voltage gives an increased line drop. The former is always a stable, and the latter may be an unstable condition.

For good system stability, it is necessary to counteract the effects of a live load by adding equipment that will give a rapid decrease in the line drop whenever the voltage falls. A static condenser is of no use for this purpose, as the current falls with the voltage, and thus the voltage rise it produces falls also, increasing the instability. An induction voltage regulator can be used, but its effect is secured by the action of its control mechanism, and so is not immediate. On the other hand, a synchronous condenser fulfills the desired conditions, as it gives an increased leading current when the voltage falls, and vice versa. The action in this case is immediate, as the field excitation is always equal to the sum of the values required to produce the voltage and the armature current, and any decrease in one results in an equivalent increase in the other. This property of the synchronous condenser is of the greatest importance in problems of system stability.

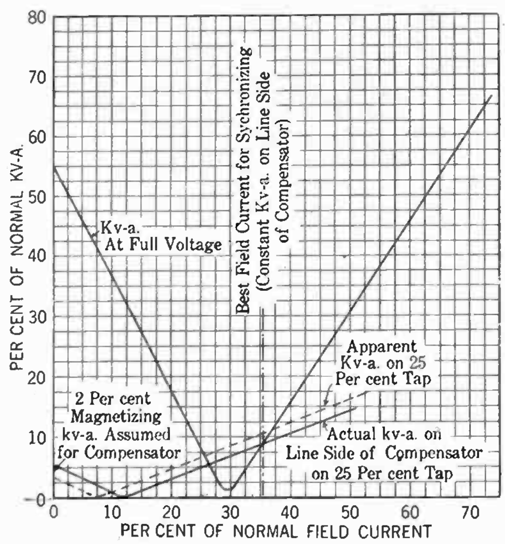


Fig. 5—Voltage Curves of a 7500-Kv-a. Synchronous Condenser

Showing method of determining best field current for synchronizing

A standard synchronous condenser with about 50 per cent lagging kv-a. capacity has a pull-out torque of about 175 per cent of its rated kv-a., with full excitation. At no-load, the pull-out torque is reduced to about 75 per cent, and even with zero field current, corresponding to full lagging kv-a., it still has a pull-out

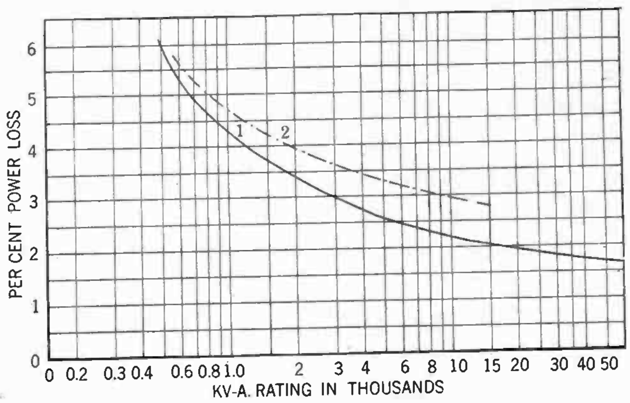


Fig. 6—Power Losses of Synchronous Condensers

Corresponding to usual manufactures guarantees

torque of about 20 per cent of its rating. A condenser designed for 100 per cent lagging capacity has corresponding pull-out torque values of about 225, 125, and 30 per cent. A standard condenser of 5000 kv-a., or above, also has a value of $W R^2$ equal to:

$$W R^2 = (6 \text{ to } 8) (\text{kv-a.}) \left(\frac{1000}{\text{rev. per min.}} \right)^2 \text{ lb. ft. squared} \tag{6}$$

The familiar equation for the torque required to produce angular acceleration in a rotating mass can now be applied to determine what rate of change of frequency can occur without the condenser falling out of synchronism. This equation is:

$$\frac{W R^2}{g} \frac{d w}{d t} = \text{torque}, \tag{7}$$

where the moment of inertia in pound-feet-seconds squared is:

$$\frac{W R^2}{g} = \left(\frac{7}{32.2} \right) (\text{kv-a.}) \left(\frac{1000}{\text{rev. per min.}} \right) \text{ approximately}, \tag{8}$$

the angular acceleration in radians per sec. squared is:

$$\frac{d w}{d t} = w \left(\frac{d w}{w d t} \right) = w \frac{d f}{f d t}$$

$$= \left(\frac{2 \pi}{60} \right) (\text{rev. per min.}) \frac{d f}{f d t}, \tag{9}$$

and the torque in foot-pounds is:

$$\text{Torque} = (0.2 \text{ to } 1.75)\ \frac{7040\ (\text{kv-a.})}{\text{rev. per min.}} \qquad (10)$$

Substituting these expressions in (7), we find the allowable rate of change of frequency for a standard condenser to be:

$$\frac{d f}{f\, d t} = 0.06 \text{ for zero field excitation}$$

$$= 0.23 \text{ for no-load excitation}$$

$$= 0.55 \text{ for full-load excitation} \qquad (11)$$

This means that the frequency could be changed 55 per cent per sec. without causing a standard condenser operating at rated field excitation to fall out of step, *provided the voltages at its terminals were held absolutely constant and balanced.* In practise, a system disturbance usually both lowers and unbalances the voltage, so the actually allowable rate of frequency change is much less.

The torque developed varies as the square of the voltage with no field excitation (full lagging operation), and just a little faster than the first power of the voltage at normal excitation (full leading operation). If one line terminal is opened, the condenser operates single-phase, and has a pull-out torque about 70 per cent of its value at the same voltage three-phase. If, however, the voltage between two terminals falls very far, corresponding to a short circuit between lines, the short-circuited phase acts as a generator feeding power to the fault, and the pull-out torque is reduced still more. Also, the existence of reactance in the lines and transformers may greatly reduce the pull-out torque. On the whole, therefore, taking into account these factors and remembering that the maximum torque of a synchronous machine is not fully available, due to the hunting that always occurs on disturbances, it is probable that not more than 10 per cent of the rate of frequency change given by (11) is permissible.

Our conclusion is that a condenser operating at rated field current will stay in step during system disturbances if the frequency does not change more rapidly than 5 per cent per sec.; and at zero field current it will stay in step during frequency changes up to ½ per cent per sec. If it falls out of step when the field excitation is very small, the condenser will behave like an induction motor and will come right back into step after the disturbance is over, while at large excitations, it will come to rest and must be restarted, hence, the lessened stability of a condenser at reduced excitations is not of particular importance. On the basis of these figures, it seems that standard condensers have ample synchronizing power for ordinary applications and that no weight need be attached to this factor in writing condenser specifications.

VIII. Recent Improvements in Condenser Design

Designers are always striving to make more efficient, cooler, and more reliable machines without increasing the cost, and the results of their efforts should at intervals be recorded. There are several recent improvements in condenser design that seem worth presentation here.

The design of amortisseur windings, especially the end rings, has always presented a serious problem on large high-speed machines, as the support of the projecting bars and rings has proved mechanically difficult. Furthermore, the presence of a complete end ring has been very inconvenient in taking down and reassembling the poles. By simply omitting any end-ring connection between poles, the amortisseur winding bars can be shortened, and the ring segment placed close to

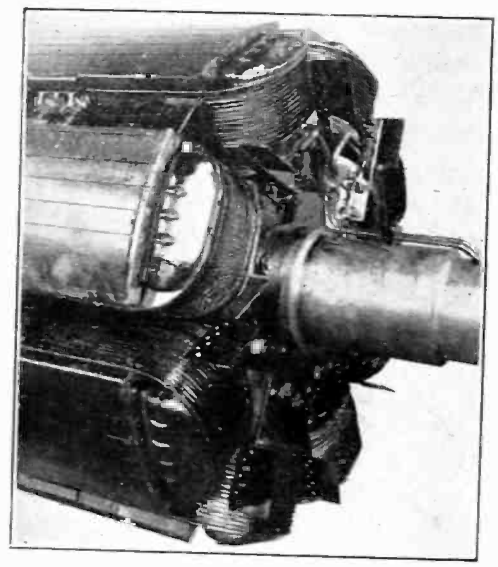


Fig. 7—Rotor of 7500-Kv-a., 900-Rev. Per Min. Synchronous Condenser
Showing open amortisseur winding and finned field coils

the pole piece punchings. The expansion of the bars due to heating during starting is taken care of by leaving a small axial clearance between the rings and the pole pieces. This gives a very happy solution to the problem, as it avoids all mechanical difficulties and dangers from overheating of the exposed bars, and greatly facilitates assembly. Most advances in the art bring complications in their train, and it is therefore extremely pleasant to be able to record one that simplifies the design instead. Fig. 7 illustrates this construction.

Another recent improvement in rotor design consists of the addition of fins to the ends of the field winding, also illustrated in Fig. 7. These fins are made by simply projecting every second or third turn of the field coil during winding. They give an increased area for cooling on the ends, where it is most effective, and so reduce the field temperature.

In the design of the stator, improvements have taken the form of simpler and stronger mechanical construction by the use of steel plates welded together instead of castings, and in improved arrangements for ventilation. Fig. 8 shows a 10-pole, 20,000-kv-a., 720 rev. per min., 11,000-volt, synchronous condenser recently built.

The welded frame is much lighter than an equivalent casting, and is more easily modified to meet special requirements.

The number of cubic feet of ventilating air passing through an open machine is so great that astonishing amounts of dirt can collect on the windings in a short time. For every kilowatt of loss, a machine requires about 100 cu. ft. of cooling air per min., or, on the basis of 8000 hrs. of operation annually, about 50,000,000 cu. ft. each year.

The air found in ordinary buildings usually contains between 0.02 and 0.2 lb. of dust per 1,000,000 cu. ft.,[6] and we may take 0.03 as representing reasonably good conditions. If 10 per cent of the dust in the ventilating air is deposited as it passes through the machine, then 0.15 lb. are deposited annually for each kilowatt of loss. Most large condensers have sufficient cooling air to provide for losses equal to 3 per cent of the rating

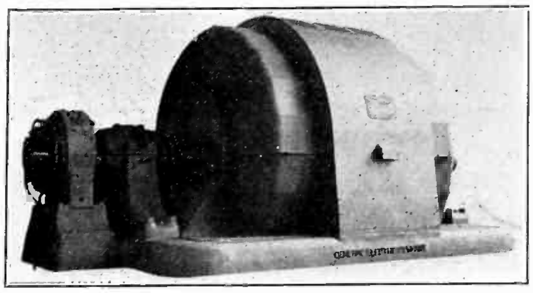


Fig. 8—20,000-Kv-a., 720-Rev. Per Min., 11,000-Volt Synchronous Condenser
Showing steel plate frame

so that this means about 4½ lb. dirt per 1,000 kv-a. of rating. On a 50,000-kv-a. condenser, this gives a total of over 200 lb. of dirt deposited annually.

The presence of dirt on the windings and in the air ducts increases, of course, both the temperature rise and the fire risk, so that the use of a closed system of ventilation prevents deterioration of the insulation and provides valuable insurance. These advantages sufficiently explain why the 50,000-kv-a. condensers recently built have been provided with closed system ventilation and water coolers. There is no doubt that an increasing percentage of large machines will be built in this way in the future.

Last, but not least, steady reductions in the losses of synchronous condensers have been going on. In Fig. 6, the usually guaranteed losses of standard condensers of voltages and speeds as given in Table I are shown in comparison with those existing four years ago. Of course, considerable variations from the curve values occur due to the special conditions in each case; nevertheless, the curve can be relied upon for preliminary calculations of the cost of condenser losses in projected installations.

6. Margaret Ingels, "How Dusty is Air," *Jl. Am. Soc. of Heating and Ventilating Engineers*, Vol. 31, Aug., 1925, pp. 415-418.

IX. Asynchronous Condensers

Asynchronous condensers, made by exciting a slip-ring induction machine from a direct-connected, a-c. exciter, are sometimes used abroad. They have the advantages of affording a large lagging kv-a. capacity, and of remaining in step through severe system disturbances. They require a distributed rotor winding, however, which results in a large extra cost and much lower efficiency. With the short time settings of protective relays generally used in this country, the extra stability is of no importance, and so their disadvantages mentioned far outweigh their advantages.

Finally the important advantage of synchronous condensers in stabilizing the voltage, discussed in section VII, is lost with the simplest form of asynchronous condenser, which has its a-c. exciter fed from a transformer connected to the main lines. For, in such a machine, the exciting current decreases proportionally to the line voltage, and so the leading current decreases also, making the apparatus equivalent to a static condenser only. This defect can be overcome by providing an auxiliary motor-driven synchronous generator to feed the exciter, at some extra expense, when the machine becomes equivalent to an unsaturated synchronous condenser.

X. Conclusions

From this discussion, several fairly definite conclusions can be drawn. These may be listed as follows:

1. The most economical speeds and voltages for synchronous condensers are approximately those listed in Table I. If quiet operation is important, it should be secured by enclosing features rather than by resorting to lower speeds.

2. Standard synchronous condensers have ratios of lagging to leading kv-a. capacity of approximately 0.5. To require a ratio of unity means an increase in size of about 25 per cent above standard, together with a slight sacrifice in efficiency.

3. To obtain greater lagging kv-a. capacity, reconnection or variable voltage operation of synchronous condensers is not generally desirable, but may be justified in special cases.

4. The use of reactors to supplement the lagging kv-a. capacity of standard synchronous condensers offers many advantages, and may be generally preferable to the use of special condensers with large lagging capacities.

5. The standard method of starting synchronous condensers as induction machines on reduced voltage is preferable to the use of a starting motor. If especially low starting kv-a. are desired, oil pressure starting equipment should be provided.

6. The least disturbance on synchronizing will take place when the field current at changeover from the tap

to full voltage is made equal to $(T + 1)$ times the no-load field current, or, roughly, 40 per cent of the rated field current of a standard condenser.

7. Present standard condensers have adequate synchronizing power, and should stay in step on system disturbances in which the frequency does not change faster than 5 per cent per sec. at rated excitation, or one-half per cent per sec. at zero excitation.

8. The use of asynchronous condensers presents no important advantages over the usual synchronous condensers, and is accompanied by a sacrifice in cost and losses.

The author wishes to express his appreciation of the assistance given him by Messrs. L. W. Riggs and O. A. Gustafson in the preparation of this paper.

Bibliography

"Synchronous Condensers in High-Tension Systems," J. W. Andree, *Elec. World*, Vol. 74, pp. 564-7, Sept. 13, 1919.

"Synchronous Condensers," E. B. Plenge, *Gen. Elec. Rev.*, Vol. 23, pp. 143-46, Feb. 1920.

"Large Waterwheel Generators and Synchronous Condensers," M. C. Olson, *Gen. Elec. Rev.*, Vol. 23, pp. 147-152, Feb. 1920.

"Automatic Control of Synchronous Condensers," D. W. Ellyson, *Elec. Rev.*, (Chicago), Vol. 79, pp. 843-846, Dec. 3, 1921.

"Synchronous Condensers for Voltage Regulation," Frank V. Smith, *Elec. Jl.*, Vol. 20, pp. 281-285, Aug. 1923.

Waterwheel Generators and Synchronous Condensers for Long Transmission Lines, M. W. Smith, Jl. A. I. E. E., Vol. 42, pp. 894-903, Sept. 1923.

Voltage Control of Long Lines by Use of Synchronous Condensers, John A. Koontz, Jr., Jl. A. I. E. E., Vol. 42, pp. 1255-1256, Dec. 1923.

"Use of Synchronous Condensers with Three Winding Transformers," R. C. Bergvall, *Elec. Jl.*, Vol. 21, pp. 205-206, May 1924.

"Operation of Synchronous Motors for Power-Factor Correction," S. H. Mortensen, *Power*, Vol. 62, pp. 204-7, Aug. 11, 1925.

"7500-Kv-a. Synchronous Condenser," J. Ricaleno, *Bul. de la Alsacienne*, April 1926.

Research

Annual Report of the Committee on Research*

To the Board of Directors:

1. The Training of Research Workers

There is, perhaps no more important problem at this time than that of the training of research workers and engineers. The popular appreciation of research is increasing. This is good because the chief stimulus of research is a certain state of mind akin to, but more than, curiosity and inquisitiveness which without doubt can be developed in the proper atmosphere. It was a similar state of mind, a dissatisfaction, a desire to go where others had not gone and see what others had not seen that actuated our pioneer ancestors and resulted in America. It would thus seem that the right material should be available; but more than material and popular appreciation is required to create the necessary state of mind. Are our colleges doing their part? As was pointed out in the report of this Committee last year, indications are that they are not. As a gage on the research in electrical engineering at colleges, Dr. F. E. Terman, of Stanford University, has made a statistical study of research papers presented by college professors and their students. The following is quoted from his report which appeared in the April 22, 1927 of *Science:*

"The summary of this survey shows that the electrical engineering schools of our country produce about one-eighth of the electrical and radio research that is reported in the pages of the national engineering societies. This represents about eleven articles a year. Of these eleven articles coming from the colleges each year, approximately seven come from four universities. There is a total of several hundred. Apparently not over a dozen technical schools are making much effort, if any, in the way of research. Over half of the university research in electrical engineering is the work of eight men.

This is the situation, and it now remains to consider the consequences of this condition. University research in electrical engineering is primarily significant as an indication of the situation which exists today in the education of electrical engineers. The laboratories of the big electrical companies make technical progress assured even without university research, but the country's supply of technically trained young men can come only from the university."

These facts are disconcerting. In correcting this condition, it must be kept in mind that true research workers are more than mere readers of instruments and collectors of data and cannot be turned out mechanically.

It is not a mere matter of money and apparatus; atmosphere and inspiration are necessary. These must be supplied. There is, perhaps, something still to be done by the industry in further recognition of the research worker in a monetary way.

2. Active Research

This Committee serves as the Advisory Committee on Electrical Engineering to the National Research

*Committee on Research:

John B. Whitehead, Chairman
F. W. Peek, Acting Chairman

Edward Bennett,	B. Gherardi,	E. W. Rice, Jr.,
V. Bush,	V. Karapetoff,	D. W. Roper,
E. H. Colpitts,	A. E. Kennelly,	Clayton H. Sharp,
E. E. F. Creighton,	M. G. Lloyd,	C. E. Skinner,
W. F. Davidson,	C. E. Magnusson,	Harold B. Smith,
W. A. Del Mar,	Harold Pender,	R. W. Sorensen.

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927.

Council. At the request of that Council, the Committee on Research has been instrumental in establishing in the National Research Council, a Committee on Electrical Insulation. This has given work of a definite character to the Committee on Research and a small group of its members has been active in this connection.

The Committee on Insulation, largely made up of members of the Committee on Research, has already made two reports; the second of which is a comprehensive review of the literature and present information on the subject of dielectric absorption, and has suggested channels for further research in this field. As a result, a number of researches are now under way in different universities; one of these, in Johns Hopkins University, is of special interest on the present occasion, as it is being supported by a generous fund guaranteed by Engineering Foundation.

A third report of this Committee on Dielectric Strength of Solid and Liquid Dielectrics is being presented at this meeting.

Research on cable insulation, under the auspices of the N. E. L. A., is under way in several colleges. Part of this work—Influence of Residual Air and Moisture on Impregnated Paper Insulation—has already been presented to the Institute by Doctor Whitehead.

3. Stimulation of Research

All divisions of electrical engineering offer wide opportunity for experimental study, development, and research. It is the special duty of our Committee to encourage and stimulate research, to keep in touch with the results accomplished, and to see to it that the members of the Institute and others interested are informed.

To do this, the Committee asks its members to report on all matters of the following natures that come to their attention:

1. New experimental work about to be undertaken. Information assists in co-ordination and often prevents duplication.

2. Important results of completed research. Information is necessary for our annual report.

3. Suggestions of important problems for research. The Committee has frequent opportunities for suggesting promising problems for experimental attack.

4. Any method or occasion which suggests itself for obtaining important research papers for the Institute.

President Chesney has done much to stimulate research in his inspiring talks at our various Sections in the United States and Canada. While he has pointed out clearly the necessity of pure research and adequate support of our colleges, he has not let us forget that the work cannot go on by research alone. Combined with this research spirit of adventure, there must be the spirit of cooperation and willingness of standardization at the proper time. Strange as it may seem, research and standardization must go together if the maximum prosperity is to be attained. It is well, in closing, to place the engineer by quoting from President Chesney's Chicago talk:

"The electrical engineer's hopes and aspirations turn him to the future. His spirit is essentially the spirit of progress, and, while he reveres the accomplishments of the past in which figures of men were more conspicuous than events, the changing conditions of modern day civilization still leave him the embodiment of progress. Complacent satisfaction with things as they are has ever been foreign to his nature; he is constantly striving for improvement."

F. W. Peek, Acting Chairman.

SYNCHRONOUS MACHINES—III*

Torque-Angle Characteristics Under Transient Conditions

By R. E. Doherty and C. A. Nickle
Associate, A. I. E. E. Associate, A. I. E. E.

This is the third part of a series of papers on the subject of synchronous machines. The first two were

I. An Extension of Blondel's Two-Reaction Theory,

II. Steady State Power-Angle Characteristics.

The present paper deals with the power-angle, or torque-angle, characteristics under transient conditions, namely,

A. Cyclic variation of impressed torque,

B. Sudden angular displacement,

C. Synchronizing out of phase.

It is shown, as in Fig. 6, that although the slope of the torque-angle characteristic (which is an important factor in the determination of the resonant frequency) under the oscillatory condition is greater over a large range of values of the average angle δ' than under steady operation, nevertheless in the range of normal operation, *i. e.*, from $\delta' = 0$ to $\delta' = 25$ deg., the two slopes, in the case of salient-pole machines, are practically the same. Hence, it is only in rather rare, special cases that a correction in the slope for the oscillatory condition is necessary. For such cases, equation **27** gives the correction.

Referring to condition *B*, Fig. 13 shows the steady state torque-angle characteristic and also the characteristics for the condition of sudden angular displacement, the latter occurring from various given points on the steady state curve. The slopes indicated by dotted line segments in Fig. 6 merely correspond to parts of the complete characteristics shown in Fig. 13. The latter are calculated from equation **46**.

It is fairly well known that synchronizing out of phase gives rise to much larger torque than would exist at the same angular displacement under steady operation. The difference between these two torques is shown in Fig. 17 for a steam turbine type generator. The steady state torque is calculated from equation **26**; the transient torque from equation **61**.

**Synopsis of paper presented at the Winter Convention of the A. I. E. E. New York N. Y., Feb. 7-11, 1927. Complete copies upon request.*

High-Voltage Oil Circuit Breakers for Transmission Networks

BY ROY WILKINS[1] and E. A. CRELLIN[1]
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THE standards of the American Institute of Electrical Engineers define an oil circuit breaker as a "device (other than a fuse) constructed primarily for the interruption, in oil, of a circuit under infrequent abnormal conditions." Common usage, however, has sanctioned the use of the term "circuit breaker" as applying to a device for the regular and usual interruption of an energized circuit as distinguished from a switch used only for opening circuits which are de-energized or not carrying load. This paper will consider only high-voltage oil circuit breakers, the term "high voltage" being taken as applying to potentials of 25,000 volts or above.

The fundamental purpose of a high-voltage transmission network is to deliver power with a maximum of reliability at a minimum expense.

The high-voltage oil circuit breaker is an integral part of a transmission network. It is purchased not to demonstrate whether or not it will fail under operating conditions, but to insure service under both normal and abnormal conditions.

In every paper on transmission line stability presented before the Institute during the last five years, the importance of fast and accurate switching has been emphasized. The present paper proposes to outline in a general way how present day high-voltage oil circuit breakers fulfill some of the operating requirements of transmission networks.

It may be said that oil circuit breakers are in use today only because no better substitute has been developed. In them, the function of the oil is to insulate the contacts one from another and from the tank or ground. Mineral oils with a relatively high flash point are the only insulating mediums thus far available. It must be noted, however, that during the time of arcing the oil is a decided detriment to the breaker. It becomes volatilized and builds up excessive pressures in the container, and it becomes ionized and forms a conducting path which aids rather than hinders the arc. If it were possible to so construct a breaker, it would be better to separate the contacts the required distance and then introduce the oil at the zero point on the voltage wave. This is not a practical possibility and it is therefore necessary to have the contacts immersed in oil at all times.

Many substitutes for oil have been proposed and tried with varying degrees of success, and of these a high vacuum seems to offer the greatest possibility of an ultimate solution to the problem.[2] A one-half inch travel of contacts in a high vacuum is equivalent to a great many inches of travel under oil, and many possibilities present themselves. The practical application of the knowledge is a real problem. An exceptionally high vacuum must be continually maintained under service conditions, and means must be developed for moving the breaker contacts the necessary inch or so within this vacuum before the switch can be made ready for general application. Of the other alternatives to oil, mostly hydrocarbons, which have been tried, none so far has been able to supplant the petroleum derivatives except for very special uses and even then only to a limited extent.

From the foregoing it is seen that there is no immediate prospect of using any current interrupting device for the control of high-voltage transmission networks other than the oil circuit breaker using a mineral oil as the insulating medium. It must therefore be the foundation upon which to base the immediate developments to secure improvements which will better fit it for the duties it must perform. That improvements are necessary and urgently needed is obvious to all operating men.[3]

The object of an oil circuit breaker is to interrupt current. For the purpose of this discusssion the characteristics of the interruption may be divided into two general groups, which may each be further subdivided for special consideration as follows:

I Characteristics influenced by the operation of the oil circuit breaker.
  a. Speed of break
  b. Current (to a limited extent) to be interrupted.

II Characteristics dependent upon the connected circuit.
  a. Power factor,
  b. Recovery voltage,
  c. Phase balancing,
  d. Growth and decay of current values,
  e. Resonance.

The subheading, I-a, may be still further subdivided for a study of the manner in which the speed of break is controlled:

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Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Calif., Sept. 13-16, 1927.

2. *Vacuum Switching Experiments at California Institute of Technology*, R. W. Sorensen and H. E. Mendenhall, A. I. E. E. JOURNAL, December, 1926, p. 1203.

3. A. I. E. E. TRANS., Vol. 43, 1924, pp. 656-657. and *Elec. World*, Feb. 5, 1927, p. 302.

I-a. Speed of break.
- 1. Speeding up moving parts by,
  - a. Spring retracted contacts,
  - b. Accelerating springs,
  - c. Quick break contacts,
  - d. Explosion chamber contacts.
- 2. Multiple breaks.

The manner in which the speed of break is affected by the several methods listed above will be considered as exemplified in present day operating practise.

a. Spring retracted contacts were first used extensively on oil immersed fuses which were in reality oil circuit breakers with a fuse as the tripping mechanism.

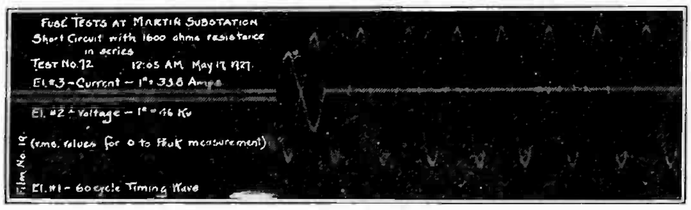

FIG. 1

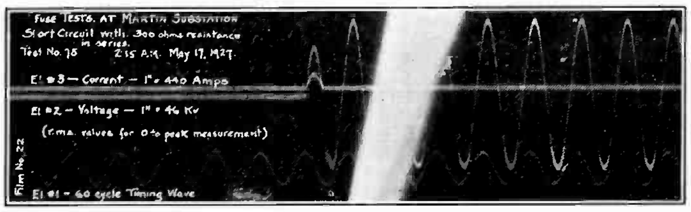

FIG. 2

They were developed and used in Europe prior to 1904 and have been thoroughly described in the technical journals of the time.[4] Letters patent covering this type of apparatus were granted in the United States in 1905.[5] This type of equipment is doubly interesting at the present time because the surviving examples represent at the same time the highest contact speed and the smallest physical dimensions of commercial current interrupting devices for use on high-voltage circuits. The speed of break attained in a 1½-ampere, oil filled spring retracted fuse with 7-lb. (3.17 kg.) pull is approximately 40 ft. per sec. (13.1 m. per sec.). An example of its performance with 1600 ohms resistance in series is given in Fig. 1 and with 300 ohms series resistance in Fig. 2. Both tests were made in the short-circuited phase to ground connection of a grounded Y 110-kv. circuit.

b. Accelerating springs are used at present on most of the high-voltage oil circuit breakers. They may be compression or tension springs or both, and in some cases both types may be found in the same breaker. Such springs are for the most part extended or compressed, (depending upon the type), by the final action of the closing mechanism of the breaker and serve both as a damping agent on the closing stroke and for acceleration of the contacts on opening. In certain cases, the contacts themselves serve such a purpose, as for instance in the Westinghouse butt contacts, which are spring-supported or the condit contacts which are of laminated leaf copper type. The effect of these contacts can be seen clearly in the accelerated travel of the moving member, which slows down again after the contacts part. See Fig. 6.

There are two major objections to the accelerating springs in general use. First, their effect is minor so far as a reasonable amount of speed in concerned, the maximum recorded being about one-half ft. per sec. (15.2 cm. per sec.); and second, they absorb energy at a time on the closing stroke when it cannot well be spared from most types of closing mechanisms. If greatly strengthened, they give rise to uncertain closing and hair trigger adjustments, already too much condemned by operating engineers to require further discussion. Suffice it to say that present day breakers require too many critical adjustments, and development must be toward a reduction in their number rather than any tendency to make them more critical.

c. Quick break contacts usually take the form of auxiliary contacts and serve two purposes,—first, to increase the separation betwen contacts in a given

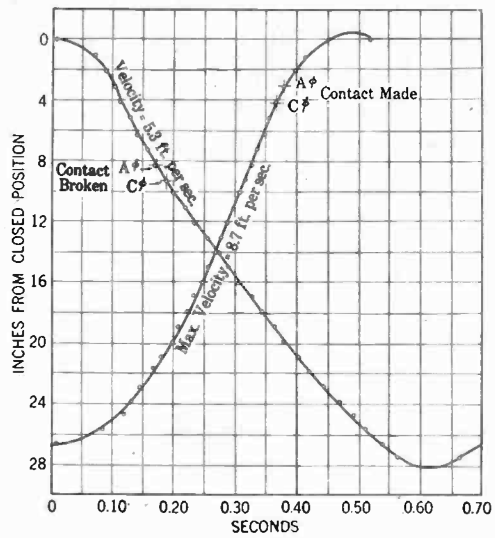

FIG. 3—CALIBRATION OF POSITION INDICATOR—110-KV., 400-AMPERE OIL CIRCUIT BREAKER

Vaca—Dixon Substation—June 20, 1926

time, *i. e.*, to reduce the time of arcing, and second, to preserve the main contact surface by breaking the arc on replaceable auxiliary contacts.

From an operating standpoint the time and energy required to operate the quick breaks is an advantage to the oil circuit breaker, gained at the expense of the system on which it operates. This comes about by reason of the fact that all varieties of quick break contacts now available delay the opening time until the contacts have traveled a sufficient distance to bring the quick break into action. Figs. 3 and 4 show the speed

4. *Elektrotech. Zeitsch.*, June 9, 1904, F. Collischonn.
5. Patent No. 781,347 to Christian Kramer, Jan. 31, 1905.

time curve of a Pacific Electric Manufacturing Company, 110-kv., 400-ampere, six-break, oil circuit breaker with contacts arranged as shown in Fig. 5. In this case, the main contacts part after 3 or 4 in. (7.5 or 10 cm.) of travel from the closed position, whereas the arcing contacts do not part until 8 or 10 in., (20 or 25 cm.) of travel has been obtained. This requires 0.075 sec. or more than 4 cycles on a 60-cycle system.

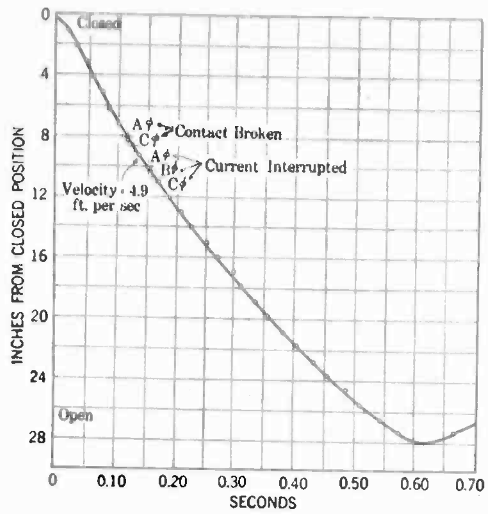

Fig. 4—Interruption of Pit Line Charging Current with 110-Kv., 400-Ampere Oil Circuit Breaker

Vaca—Dixon Substation—July 12, 1926

Fig. 6 shows the speed—time curve for a Westinghouse Type G-2, 187-kv. oil circuit breaker of the type used on a 220-kv. grounded Y system in which the quick break contacts have the form shown in Fig. 7. With this breaker, the main contacts part about 1½ in., (4 cm.) from the closed position and the quick break auxiliary contacts about 10 in. (25 cm.) from the closed position. This requires about 0.25 sec. or 15 cycles on a 60-cycle system. The speed obtained on the quick break contacts themselves is about twice that of the main contacts so that the arc when started is extended at about three times the main contact speed.

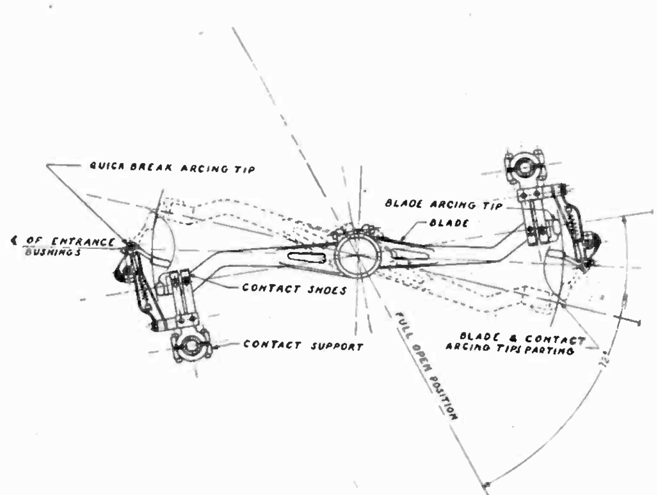

Fig. 5—Details of Contacts, Pacific Electric Oil Circuit Breaker

d. Increased contact speed may also be gained through the use of the explosion chamber type of contacts. These are a development of the original Type *H*

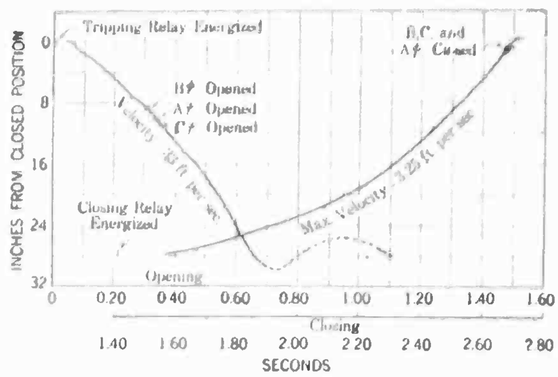

Fig. 6—Position Indicator Calibration

Westinghouse type G-2, oil circuit breaker, with rotating release arcing tips, at Vaca—Dixon Substation—June 26, 1926

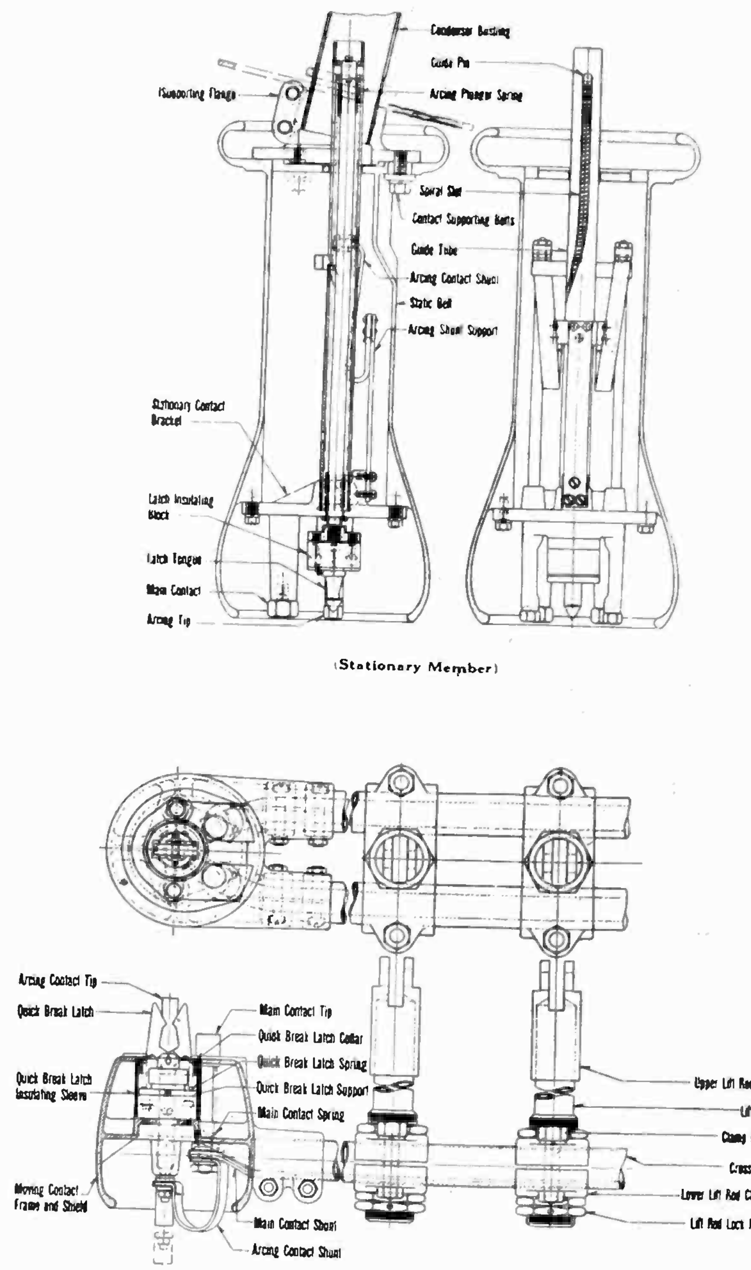

Fig. 7—Bayonet-Type High-Speed Contact (Rotary Form)

oil circuit breaker manufactured by the General Electric Company, and may be found in the high interrupting capacity breakers of the General Electric Company in the United States, and its affiliated companies, notably the A. E. G., in Europe. The principle of the explosion chamber contact is illustrated in Fig. 8 and is too well known to require any extended description here.

In this type of contact the speed of break is obtained by virtue of the gas pressure in the contact chamber acting on the rod as a piston. The gas pressure is

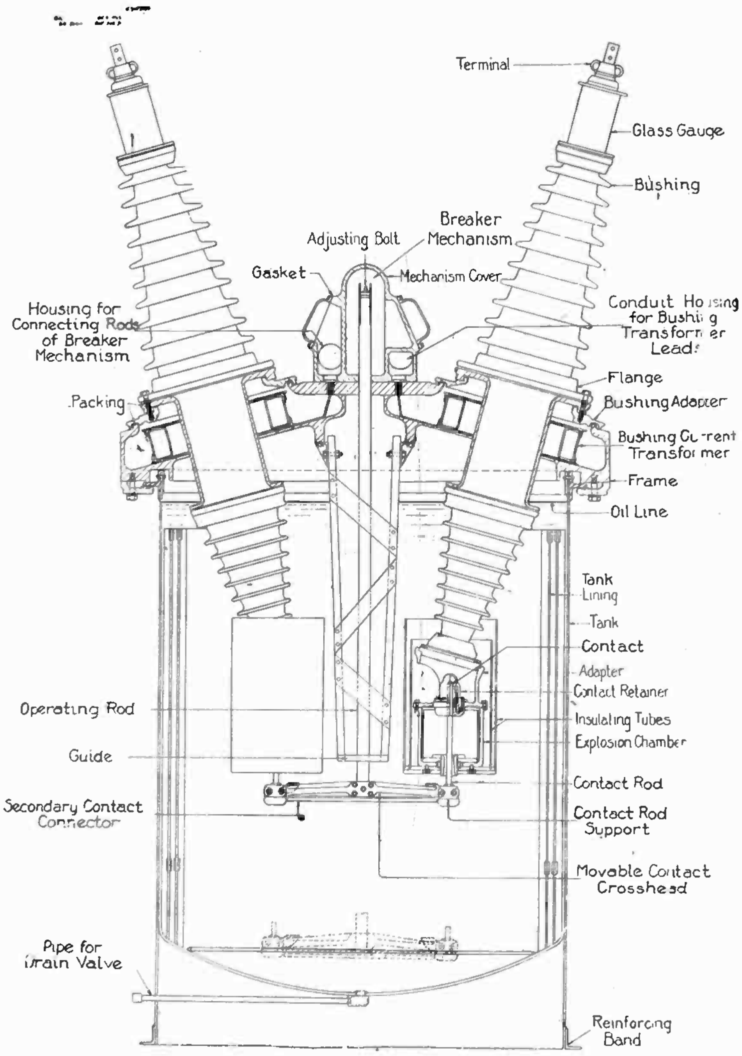

FIG. 8—TYPICAL OUTLINE OF SINGLE-POLE ELEMENT OIL CIRCUIT BREAKER, 110,000 VOLTS AND ABOVE

generated by the arc acting on the oil within the explosion chamber and depends upon the clearance between the contact rod and the explosion pot entrance bushing and the amount of oil volatilized. The amount of oil volatilized depends upon the current in the arc and the time of arcing. This means that high currents will cause increased contact speed over lower currents.

Fig. 9 shows the speed—time curve of a General Electric F H K O-36-33C, 115-kv., oil circuit breaker at no-load, and Fig. 10 shows the speed—time curves for the same breaker when interrupting 300 amperes of line charging current. In this type of contact the clearances are determined by the maximum amount of current to be interrupted and the maximum speed the contact member is permitted to attain. In the example given above, the maximum speed was 5.5 ft. per sec. (1.8 m. per sec.) while in the extensive Canton tests[6] the contact speeds were between 6 and 7 ft. per sec. (2 and 2.3 m. per sec.). The contact speeds attained at the Alabama Power Company tests[7] on explosion chamber breakers were between 4.75 and 6.6 ft. (1.56 and 2.16 m. per sec.). This type of breaker obtains increased contact speed at the expense of the oil in the circuit breaker.

The breakers thus far considered have all been of the two-break type, and the total length of arc in all makes is approximately the same. The contact speeds are also of the same order and range from 3.5 ft. (1.15 m.) per sec. to somewhat less than 7 ft. (2.3 m.) per sec. In order to better appreciate what these speeds represent, it may be well to convert them to mi. per hr., a term universally familiar to all Thus we see that 3.5 ft. (1.15 m.) per sec. is only 2.4 mi. (3.86 km.) per hr., 5 ft. (1.64 m.) per sec. is 3.41 mi. (5.5 km.) per hr. and 10 ft. (3.28 m.) per sec., 6.82 mi. (11 km.) per hr. which is only slightly above the speed of a brisk walk. Present day high-speed d-c. circuit breakers have a speed of approximately 200 ft. (65.6 m.) per sec.

Speed of contact travel is the only feature of the breaker which may be varied to reduce the time of arcing, and when it is considered that it is at present usual to ask for interrupting capacities of a million kv-a. or more, it would seem logical to greatly increase the

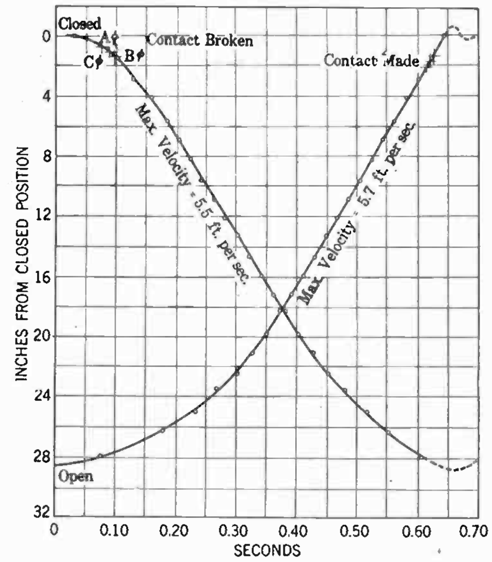

FIG. 9—CALIBRATION OF POSITION INDICATOR—115-KV., 400-AMPERE OIL CIRCUIT BREAKER
Vaca-Dixon Substation—July 10, 1926

speed of contact travel. The effect of increased contact speed will be discussed later.

Under the heading I-a, Speed of break, there still remains the consideration of the second subdivision, Multiple breaks. By common usage the term multiple break has been considered to apply to circuit breakers employing more than two simultaneous breaks in series

6. JOURNAL A. I. E. E. July, 1927, p. 698, *Tests on Oil Circuit Breakers*, by Sporn and St. Clair.

7. J. D. Hilliard, *Circuit Breaker Tests at Bessemer, Ala.*, TRANS. A. I. E. E., 1924, p. 636.

to interrupt the circuit. American manufacturers of this type of breaker are the Condit Electric Manufacturing Company (Brown Boveri type) the Kelman Electric and Manufacturing Company and the Pacific Electric Manufacturing Company. The Brown Boveri switch tested at Canton[8] was an imported breaker, but almost identical with the American built breakers of the same design. This was a type A F 24/1A, 150-kv. breaker with ten breaks in series per pole. It had a contact speed of from 1.7 to 2.2 ft. (0.56 to 0.72 m.) per sec. and a contact travel of a little less than one foot, (0.3 m.).

The Pacific Electric breaker has six breaks in series per pole, the contacts rotating to make a horizontal break. The speed—time characteristics of this breaker with a solenoid operating mechanism are shown in Fig. 4. The most recent switches of this company are equipped with a motor-wound spring-type operator which has increased its speed of operation to give a contact travel of approximately 15 ft. (5 m.) per sec.

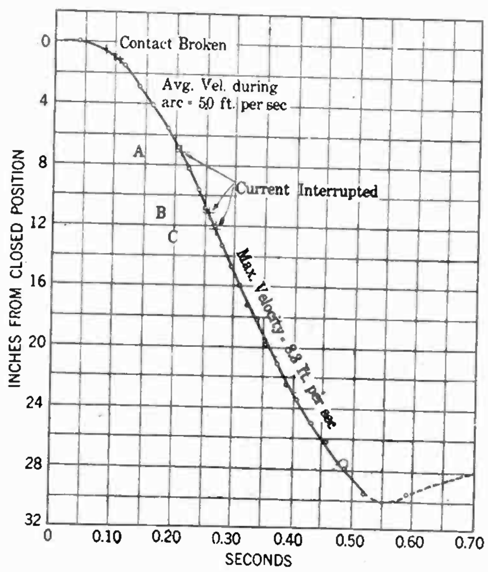

FIG. 10—INTERRUPTION OF PIT LINE CHARGING CURRENT WITH 115-KV., 400-AMPERE OIL CIRCUIT BREAKER

Vaca—Dixon Substation—July 10, 1926

with speed—time characteristic curves of the same shapeas shown in Fig. 4.

Kelman breakers also employ a six-break contact which is controlled through a pantograph mechanism to make a horizontal linear break. The breaker is solenoid operated, and has a contact travel of approximately 3.2 ft. (1 m.) per sec.

The importance of speed in clearing trouble in a high-voltage transmission network cannot be too strongly emphasized. As systems grow in size and the amounts of power available at a fault increase, it becomes more and more necessary to isolate the fault in the shortest possible time. With the large amounts of power available, great damage is done in a very short space of time and the very existence of the network depends upon the quickness and accuracy of the switching.

Relays have been developed and applied to line protection to such an extent that it is now practicable to relay a line so that troubles causing a flashover can be cleared before material damage is done to the line insulators or conductor more than 90 per cent of the time. Relays are now in operation which will close their contacts selectively on grounds on one of a pair of parallel lines in a definite direction on both ends of that line in considerably less time than is required for any available high-voltage oil circuit breaker to open its contacts after the trip coil has been energized.

It will be shown later that the time required to open the contacts of a present day high-voltage oil circuit breaker is roughly one-half the total time required to clear the average case of trouble. Exception to this is made in the case of the breakers with explosion chamber type contacts where the time is greater or less dependent upon the particular design and the current to be interrupted. It is therefore evident that the time consumed by the relays in discriminating between circuits and starting the necessary operations to trip the switch is approximately only one-third of the total time required to clear the circuit. The balance of the time is taken by the oil circuit breaker itself in completing the interruption and is unnecessarily long. That increased speed is desirable seems to be universally accepted. The best method of achieving this increased speed seems very much debated. From an operating standpoint, however obtained, higher interrupting speeds would benefit both the breaker itself and the system of which it was a part.

LIMITATION OF CURRENT

In the foregoing outline under subheading (b) as a characteristic of the circuit interruption influenced by the oil circuit breaker was given the limitation of the current to be interrupted.

In such breakers as have this feature incorporated, it is usually accomplished by the insertion of resistance into the circuit before the final rupture takes place. European breakers use this feature much more often than those manufactured in America, one reason being that the greater proportion of European oil circuit breakers are multiple contact and lend themselves particularly well to such treatment.

The mechanical design of high-voltage oil circuit breakers is not yet advanced to a point where the resistance feature can be added without reducing the mechanical reliability of the breaker below a safe minimum in many cases.

However, low-voltage circuits for heavy duty are, customarily equipped with external reactors to reduce the duty on the oil circuit breaker and are considered sound practise even though they entail a continuous loss often for the sole purpose of protecting the oil circuit breaker momentarily during trouble.

8. Sporn and St. Clair., *Tests on Oil Circuit Breakers*, JOURNAL A. I. E. E., July, 1927, p. 698.

The expense and operating difficulties attending the use of external reactors for high-voltage work has prohibited their use for 60 kv. or above, except in a few isolated cases. The mechanical difficulties attending their use internally on a two break oil circuit breaker have likewise prohibited their use in that direction in this country.

Characteristics Dependent Upon the Connected Circuit

As subheadings under those characteristics over which the oil circuit breaker has no control are grouped: (a) power factor, (b) recovery voltage, together with others to be considered later.

Because of the fact that the current in an a-c. circuit is broken at or near the zero of the current wave the duty on the breaker is least at unity power factor since the voltage across the contacts is also zero at that time. With a decrease in power factor two things happen:

First: The voltage available to strike across the gap and reestablish the arc is higher being a maximum at or near zero power factor since the voltage is a maximum when the current is zero at that time.

Second: Since the character of the circuit interrupted determines the character of the voltage wave across the contacts, the arc voltage on inductive circuits has the characteristic horns as discussed in many texts.[9]

These horns for metallic electrodes under oil are very sharp, frequently too sharp to be recorded satisfactorily on the commercial oscillograph and are often equal to or slightly greater than the nominal circuit voltage at the time of interruption.

Contrary to the usual idea, system stability tests have demonstrated that in practise the power factor of a ground on a high-tension network may have been reasonably good and operating practise has determined also that by far the major portion of high tension network troubles are from conductor to ground.

In practise, therefore, the power factor of the circuit, while important, is not vital to an oil circuit breaker with any reasonable margin of safety except in special cases which will be considered later. Coupled with power factor is recovery voltage usually defined as the voltage across the oil circuit breaker contacts in the first half cycle after the circuit is interrupted.

The only thing definitely established regarding recovery voltage on an operating network is that it is not the simple vector relation of normal voltages that a single generator gives on test. All of the transient characteristics of the connected equipment influence it sometimes for several cycles after the arc has cleared.

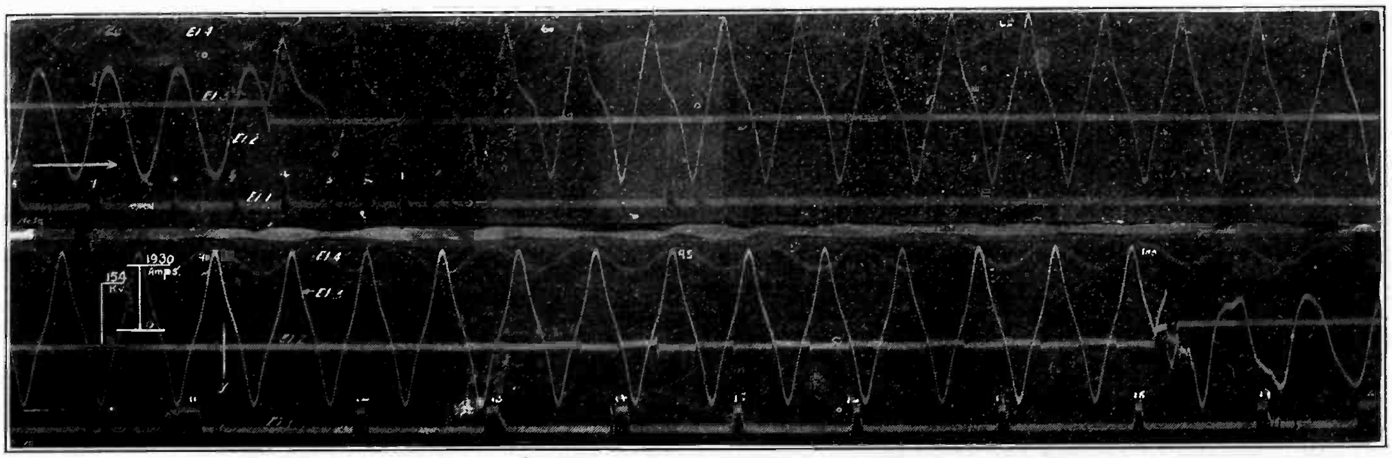

Fig. 11—Interruption of Single-Phase Ground on Pit Line No. 1 (System Connected)

Vaca—Dixon Substation—July 9, 1926
Y — B P contacts open
El. 1—Position indicator
El. 2—Arc volts B phase
El. 3—B phase current
El. 4—50-cycle timing

Phase Balancing and Growth and Decay of Current Values

In low-voltage networks and particularly in oil circuit breaker tests on a single generator the current to be interrupted begins to decrease after the first half cycle of short circuit. It is therefore, as a rule, easier for the oil circuit breaker to clear the circuit several cycles after the short circuit is applied.

Most troubles on such generators and networks are between phases so that such tests represent a practical operating condition.

High-voltage network troubles are more often from wire to ground; on the sytem of the Pacific Gas and Electric Company for instance, on 60 kv. and above, over 95 per cent of all line trouble is from phase to ground. For such conditions the initial short circuit current may be only a fraction of the final value to be interrupted.

Fig. 11 gives an oscillograph record of a wire to ground short circuit on one of two parallel 220-kv. lines with the system in normal operation cleared by relay in the

9. Alternating Current Phenomena, C. P. Steinmetz, Pages 353-357.

usual way, leaving the second line in service. The current in this case increased for some 5 or 6 cycles and was then practically constant until interrupted. This is due to the so-called phase balancing action and in some cases has given as high as a 2 to 1 ratio between initial and maximum amperes. The same thing takes place if the several phases of an oil circuit breaker do not interrupt the circuit simultaneously although this trouble is largely eliminated from present day oil circuit breakers.[10]

Resonance

Of all the phenomena occurring during the interruption of a high-tension circuit as part of an operating network, there remains the one probably the least understood,—resonance. At the instant the contacts part, an arc is established. It has a so-called negative resistance due to the fact that the initial stream of ions and electrons under the influence of a high potential gradient cause additional ions and electrons by collision. This in effect increases the area of the arc and decreases the resistance.

At the start of the break there is a relatively low potential across the arc and the effect of arc voltage is scarcely noticeable. As the contacts part the voltage across the arc increases and the current growth for each cycle is determined more and more by the characteristics of the connected circuits frequently differing greatly from the system frequency.

This ability of the arc to convert from one frequency to another is wellknown in communication but is little appreciated by transmission engineers and practically no data on the effect of series arcs in a circuit containing capacity and reactance are available.[11]

This has an immediate and practical application in high-tension oil circuit breaker practise because on every line that is cleared in trouble to ground at least two phases at one end must interrupt charging current which may or may not be the nominal charging current of that line.

In Fig. 11 was given a record of the interruption of a single-phase 220-kv. ground of some 2430 amperes.

Fig. 12 gives the record of the same oil circuit breaker on the same 202-mi. line interrupting 156 amperes of charging current at 220 kv.

The length of arc, slightly under 19 in. per contact, was the same, the contact burning the same so far as visual inspection could determine, and the deterioration of the oil the same. Figs. 13 and 14 give these plotted in the form of curves.

It is to be noted that after the first two cycles the current builds up at the natural period of the line to values much in excess of the normal 60-cycle charging current, the speed of current growth being greater for short sections of line since the characteristics change for them.

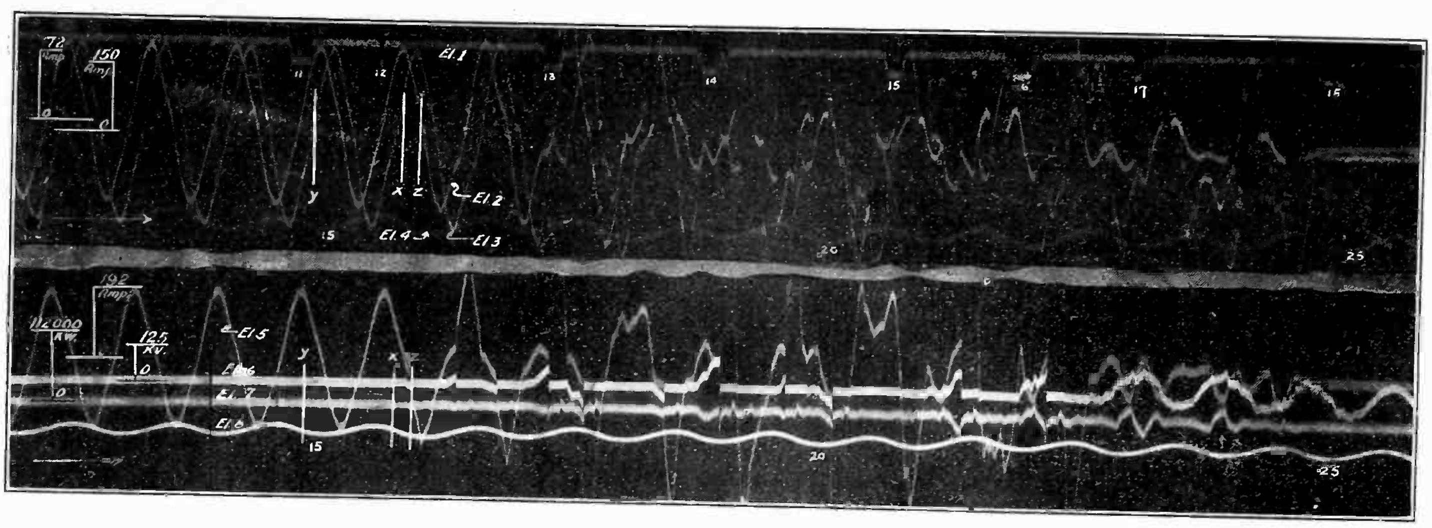

Fig. 12—Pit Line Charging Current Interruption at 220 Kv.

Vaca—Dixon Substation—June 26, 1926

X—A-phase contacts open
El. 1—Position indicator
El. 2—C phase current
El. 3—A phase current
El. 4—50-cycle timing

Y — B phase Z — C phase
El. 5—B phase current
El. 6—Arc volts B phase
El. 7—Arc watts B phase
El. 8—50-cycle timing

In practise such records have been taken for several makes of 110-kv. oil circuit breakers for identical conditions using the several methods of increasing contact speed from two break breakers with a speed of less than 4 ft. per sec. per contact to 6-break breakers with a speed of 15 ft. per sec. per contact and a range of arcing time from 12 cycles on the slower speed to 2 cycles on the higher speed.

The total arc length increases for a given duty on most types as the speed increases at some rate less than the speed increase, *i. e.*, a 6-break oil circuit breaker has a greater total arc length, but a much shorter length per

10. *Practical Aspects of System Stability*, R. Wilkins, A. I. E. E. Trans., Vol. XLV, 1926, p. 41, (Fig. 7).

11. C. P. Steinmetz, *Frequency Conversion by third Class Conductor*, A. I. E. E. Trans., Vol. XLII, 1923, p. 470.

contact than a two-break oil circuit breaker for the same duty.

The important point often overlooked is that the high-speed breaker clears the disturbance in much less time with much less damage both to the system and to the breaker.

There is no virtue in making an elaborate contact arrangement and then slowing the whole mechanism down to the same total speed as a simple one break breaker. But a breaker which will clear a given trouble in one or two cycles is a much more satisfactory piece of apparatus than one requiring 15 cycles, provided it can be properly relayed and made to stay together.

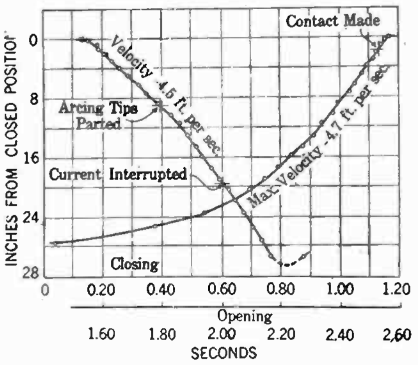

FIG. 13—SINGLE-PHASE GROUND ON PIT LINE NO. 1

Equipped with rotating release arcing tips. Breaker tripped out by station relays. Line connected to System, at Vaca—Dixon Substation—July 9, 1926

CONCLUSIONS

Throughout this paper the viewpoint on controversial subjects has been from the practical side; that is to say, from the position of the operating man rather than the manufacturer. This as is it should be, for design must meet the requirements of the operating man who purchases and uses the apparatus.

The primary assumption has been made that the function of a transmission network is to deliver power with a maximum of reliability at a minimum expense. The oil circuit breaker is an integral part of the network and has a particular and very important function to perform.

Engineers engaged in the design of transmission networks must now plan the network to operate in such a manner that it will not overstep the capacities of the oil circuit breakers installed. These capacities are not definitely known and therefore large factors of safety must be allowed and unnecessary expense incurred.

This is especially true in very high-voltage transmission lines, where both carrying capacity and stability are greatly improved if the lines can be broken up into sections by switching stations and only a relatively small section isolated to clear up trouble. Such a plan is not generally carried out because of the operating limitations and great cost of high-voltage oil circuit breakers. The oil circuit breaker is therefore the limiting feature to the securing of the best possible operating results in electric transmission developments involving many millions of dollars.

With the increase in transmission voltage and the large concentrations of power, there has come a new set of problems not previously encountered. The problems of transmission line stability and continuity of service are of the utmost importance because outages render large blocks of power unproductive of revenue and may cause financial loss to consumers dependent upon continuous service. The position which the oil circuit breakers hold in these problems is becoming more generally realized, their faults and shortcomings recognized and most important of all, their economic relation to the rest of the development is being clarified. This has taken time, for engineers and operators have formed the habit of unconsciously basing their decision around oil circuit breaker limitations. They had to be on the safe side, and what would have been the best solution of a problem may have been discarded in place of a plan less favorable from economic or operating results, but more sure of success because the circuit breakers could not be considered as highly reliable pieces of apparatus to guarantee the carrying out of the most desirable plan.

Certain fundamental requirements may be set down as essential in an oil circuit breaker for use on high-voltage transmission networks. To meet these requirements with present day knowledge of oil circuit

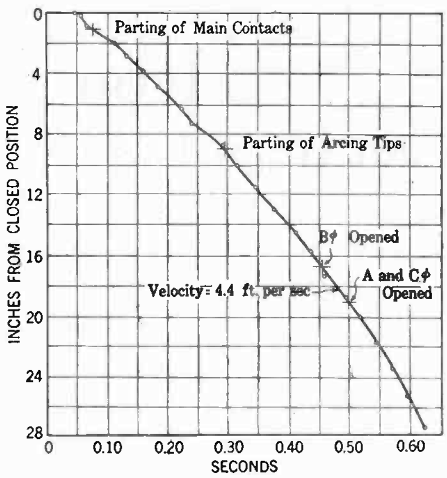

FIG. 14—PIT LINE NO. 1 CHARGING CURRENT INTERRUPTION, WITH WESTINGHOUSE TYPE G-2 OIL CIRCUIT BREAKER

Equipped with rotating release arcing tips at Vaca-Dixon Substation, June 26, 1926

breaker design requires a composite breaker embodying the strong points to be found in the designs of the several manufacturers. Briefly, these requirements are:

1. The total operating time for a complete "open-close-open" cycle of operations at rated current, and voltage shall not be more than 0.2 sec.

2. The arcing time shall approach as close as possible to the ideal of one-half cycle.

3. The energy for the switch operator shall be stored and available for instantaneous release. The mechanism should not have a power demand in excess of one kw.

4. The breaker shall be capable of completing 100 normal operating cycles before any inspections or adjustments are necessary. (If requirements 1 and 2 are met successfully, there should be no trouble in reaching 1000.)

5. The breaker shall be so designed that it can be installed, adjusted and maintained by the average mechanic without especial training in oil circuit breaker technique.

The growing knowledge of the important part played by the oil circuit breaker in a transmissiion network is stimulating investigations on the part of the operating companies to satisfy themselves as to the best circuit breaker for use on a given system. As has been previously stated, it is economically unfeasible for each manufacturer to maintain equipment for the testing of oil circuit breakers with a rating of 2,000,000 or more kv-a. at 220,000 volts. Also these tests at the manufacturers' plants are not conclusive for it is impossible to duplicate the conditions met on an extensive, interconnected transmission network, where recovery voltage, resonance, surges, etc., are variable and indeterminate.

The only way in which it is now possible for an operating company to satisfy itself of the suitability of any theory of circuit breaker design, is to conduct carefully supervised tests on its own system. This requires a maximum of courage, but if reliable service is the utlimate goal, all equipment must be tried and found not wanting. Competitive designs and theories, coupled with a wide range in price quotations, all in the face of a positive refusal to give any guarantees on performance, make the selection of an oil circuit breaker for a given installation extremely difficult. Present day knowledge must be amplified by further test data.

It is entirely possible that the oil circuit breaker as now known, may not be the ultimate device for opening a-c. circuits. They are used today because they are the only devices which have been developed to the point where a reasonable dependence may be placed on their operation.

The immediate problem is to combine in one oil circuit breaker all of the good features now available in the designs of the several manufacturers. By so doing it will be possible to approach the operating requirements set down previously, and secure a breaker superior in performance to any now offered. Along with this must go continued research, looking toward the development of a device for the interruption of a high-voltage, alternating-current circuit which will be as dependable in its operation as is the transformer and generator. Pending this time, oil circuit breakers must be purchased and used with a full knowledge of their limitations.

Iron and Steel Industry

Annual Report of Committee on Applications to Iron and Steel Production*

To the Board of Directors:

The importance of electricity to the production of iron and steel has reached such magnitude that this Committee believes that all engineers should be informed as to the situation so as to be prepared to apply it successfully in all its fields of application. To this end, the Committee would outline the extent to which electricity is being applied in this industry.

Lighting

Perhaps the first application was that to lighting. The arcs were replaced by incandescent lamps and now illumination is receiving much attention as to the proper lighting of various jobs and work spaces. Proper illumination is now credited with increase in both production and safety. Steel mills, however, are not yet lighted as they should be, and increased emphasis should be placed on this phase of their work by electrical engineers.

Heating

The use of electricity for heating has increased with the installation during the past year of over 25 melting furnaces. These range from ¼ ton to 25 tons, and are of the arc type. The time of melt has been reduced considerably. The increase of production has also been greatly influenced by furnace design. The removable roof type of furnace appears to be the trend in design.

Resistor type furnaces are being used for annealing and for heat treating of alloy steels. Laboratory furnaces have been used in the steel mills for many years.

Several years ago electrical heating was applied to rolls in sheet and tin mills to increase production during the first turn after a shut down or a roll change. This use is apparently well grounded since a report by the A. I. & S. E. E. states that 168 roll heaters are in use in 19 plants. Electrical heating devices have been used in crane cabs and offices for many years.

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Presented at the Summer Convention of the A. I. E. E. at Detroit, Mich., June 20-24, 1927.

Main Roll Drives

During 1926 nearly 150 main roll drives were purchased, all of which were electrically operated. Of these only six were a-c., the rest were d-c., ranging from 230 to 900 volts. Of a special interest is the 8000-h. p., 700-volt reversing, d-c. motor drive for the 54-in. blooming mill in a Pittsburgh mill. Large motors for such drives have become common. Individual motor drives on tandem strip mills are also of interest because of their increased use. While the use of d-c. motors has predominated, a few induction motors have been installed with speed control; also, a few large synchronous motors have been applied with apparent success on their particular mills. Undoubtedly, the use of synchronous motors for mill drive will increase.

To reduction of labor and the actual improvement in the steel produced is due the importance of the electrification of steel mills. Electric drives in steel mills permit the mill designer to produce a mill that will do things heretofore impossible.

Auxiliary Mill Drives

In connection with the installation of many new main mill drives, auxiliary drives have come in for much attention, with the idea of giving closer control of these auxiliaries with fewer operators. Automatic control of screw-downs, tables, transfer cars and drag-overs, together with furnace doors and pit covers, has increased with resultant efficiency, the ratio of steel production to men employed.

The A. I. & S. E. E. has completed its specifications for auxiliary and mill motors and one motor manufacturer has announced motors built according to these new specifications.

Alternating current is gaining some ground applied to auxiliary drives, but direct current is apparently very well grounded in the steel mill electrical man's scheme of operations.

Welding

Electric welding can be mentioned briefly because it is used extensively for repair work, and indications are that in the future building construction will be influenced by this process.

Perhaps the most important application of electric welding is its use for the building up of large machines by welding plates. These welded structures are to replace castings. The ease with which complicated as well as simple structures can be made, together with their lightness and strength, is making this innovation one of importance and one which gives promise of rapidly increasing use.

Safety

Because of the wide-spread use of electricity in mills, the various electrical departments appear to be leaders in safety programs and the elimination of *all* hazards as well as those electrical. This may be because of the peculiar nature of electrical hazards, and the extensive steps taken by power companies and electricity users to eliminate these hazards and to take care of unfortunate victims. The prominent place of steel mill electrical men in the promotion of safety should be recognized.

Measurements and Instruments

The metering of electric power has been practised from the first, and its convenience has caused its more extensive use in the mills in order to determine not only the total power costs, but also the detailed operating costs down to individual machines and drives. Even auxiliary drive controllers are being specified to include permanent shunts for convenient metering. This permits proper distribution of costs for different processes.

Electricity also plays an important part in other than power measurements, such as tachometers and pyrometers for speed and temperature determinations. The metering of gases is done also readily with great convenience by electrical means.

By the increased use of electrical power measurements attention has been called to economies that are possible. These economies are watched by all departments and stimulate effort by department heads to make savings heretofore uncontemplated. Furthermore, these measurements and economies stimulate improvement of design to effect even greater economies.

Conclusion

In conclusion, it may be noted that there is considerable activity in the rebuilding of steel mills so as to produce more steel at a lower cost. The old steam drives are replaced by electric drives, most of which are for direct current.

The transmission of electric power at high voltages, together with the ease with which it can be converted for convenient application, has caused the use of electricity to drive out steam. Its use is now amply safe-guarded and engineers and operators are more skilled in its application and use. The ease with which a few mill operators can control a large number of motors through remote-control devices further demonstrates the superiority of the electric drive This rapidly increasing use of electric power demands the closest attention of electrical engineers.

The improvement in engineering that is apparent today gives a certainty of predetermination of results which is not only gratifying to the engineer, but of greatest value to the executive.

About 23,000 acres in McCurtain County, Oklahoma, are to be covered by a lake to be created by the building of four dams on the Mountain Fork River, where a paper pulp industry is developing. On the Colorado River in Texas, near Kingsland, and between Austin and Lampasas, six power dams are to be erected to impound water enough to generate 122,000 horse power of electrical energy.

The Space Charge That Surrounds a Conductor in Corona

BY JOSEPH S. CARROLL[1] and JOSEPH T. LUSIGNAN[2]

Associate, A. I. E. E. Associate, A. I. E. E.

Synopsis.—*A qualitative analysis of the nature of the space charge created about a conductor in corona, particularly with respect to relative magnitudes and polarities, rather than actual quantitative measurement, is described here. This work was the principal work on corona during the past year in the Ryan High-Voltage Laboratory.*

In tests with the arrangements of a wire and a plane, and of a wire and a cylinder, a decided rectifying effect was discernible in the space about the conductor in corona, in that that region was built up to a unidirectional potential above ground, the magnitude and polarity of this potential depending on the voltage applied. In both of these set-ups, this net rectification, which is evidently caused by some differential action entering into the ionization process, was of a positive sign at the start of corona, but changed over to negative as the voltage was raised.

In a test made on two 1.1-in. diameter, parallel concentric strand copper conductors, 10 ft. apart, the space between them was found to have assumed a potential above ground when the conductors were in corona, the sign of this charge being negative at first, and then positive as the voltage increased. Tests were also carried out on a single brush, and on a rod fitted with "artificial" brushes.

In a corona-loss curve taken on the two cable conductors it was found that at the same voltage at which the sign of the rectified space charge had reversed, there was a "break" in the curve. This "break" corresponded to the point above which Peek's quadratic law of corona holds, and below which he has suggested the entrance of a probability relation.

A final field test was made at a span of the 220-kv. Pit River Lines of the Pacific Gas and Electric Co., in order to ascertain the magnitude and polarity of the charge built up about a high-voltage line in service. A negative polarity was found to be present as far down as 30 ft. below the conductors. Although the voltage was raised to 260 kv., the charge remained negative, indicating that the line at its normal 220-kv. potential was operating at a point on the corona-loss curve appreciably below that where the break occurs in the curve.

General Experimental Study of Space Charge

The continuation of the study of the nature of the space charge that surrounds a conductor in corona was made during the past year in the Ryan High-Voltage Laboratory by attacking the problem from several different angles.[7]

One of the simplest cases giving evidence of the presence of a space charge is in the time-honored set-up of the wire at the center of a cylinder. If the cylinder is connected to ground through a condenser and a d-c. galvanometer is shunted across the condenser and then alternating voltage is applied to the wire at the center of the cylinder, the galvanometer will indicate, in the usual set-up, the presence of a unidirectional current as soon as corona appears on the wire[3]. If the galvanometer shows a deflection, it indicates that some of the space charge that is planted about the conductor is getting over to the cylinder. Since the sign of the charge leaving the conductor reverses each time the voltage reverses, the deflection of the galvanometer indicates that charges of only one sign get over to the cylinder or that more of one sign than the other gets over. With the ordinary set-up, this unidirectional current is usually from the cylinder to ground at first but as the voltage is raised the galvanometer indicates a reversal of current. The reason for this will be taken up later.

If the wire and cylinder be replaced by a wire and neutral plane, the circuit connections being the same as those described in the use of the cylinder, the results obtained will be similar.

A little more as to the nature of the space charge can be learned by the set-up shown in Fig. 1. This method has been used by several others in the past and is not given here as anything new, but only to complete the story.[3,4] If, for example, the plate is made positive with respect to the wire mesh, part of the negative ions arriving at the wire mesh will be drawn through to the plate where they will give up their charge which will then produce a deflection of the galvanometer. The relative amount of the space charge arriving at the neutral plane can be observed under different conditions with respect to voltage, size of wire, distance of wire from plate, etc. A great deal of work has been done along this line by Mr. Willis.[4] A characteristic plot of results that were obtained by the authors using the method just described is given in Fig. 2. The curves show that the positive ions reach the neutral plane at a lower applied voltage on the wire than do the negative ions. The number of negative ions reaching the neutral plane, however, increases more rapidly with an increase in applied voltage than does the number of positive ions. If it were not for the fact that a single brush from a point has almost the same characteristic curves as those

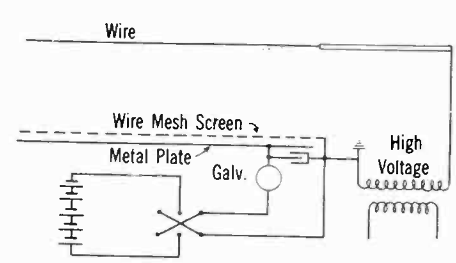

Fig. 1

1. Assistant Professor of Electrical Engineering, Stanford University.

2. Fellow in Electrical Engineering, Stanford University.

7. See Bibliography for reference.

Presented at the Pacific Coast Convention of A. I. E. E., Del Monte, Calif., Sept. 13-16, 1927.

in Fig. 2, except with reverse polarity, it might not be so difficult to offer an explanation for the form of these two curves. If high-voltage direct current is applied to the wire instead of alternating current, and the corona current plotted against the applied voltage with the wire positive and then with the wire negative, the results will not differ much in form from those shown in Fig. 2.[5] Three of the factors that help to determine the form of these curves are the mobilities of the ions, their rate of manufacture and the amount that their presence disturbs the normal field.

One of the most important things is lacking in the results obtained by means of the set-up shown in Fig. 1 and that is the time element. In other words, what is the wave form of the current produced by the arrival of this space charge at the neutral plane? Since the action is cyclic, it was a comparatively easy matter to determine the form of this wave. The set-up shown in Fig. 3 was evolved. The principle made use of here is very simple: If a charged electroscope is brought near to a conductor in corona, it will be discharged, of course, by the attraction of the ions which will neutralize its charge. Now suppose instead of exposing the electroscope continuously, a synchronous shutter be provided that will expose it for only a certain portion of the cycle. If the rate of discharge of the electroscope be noted as the shutter is operated at different phase angles with respect to the applied voltage, the determination of the wave form can be made. This synchronous shutter arrangement was obtained by means of a four-pole synchronous motor driving a 12-in. aluminum disk with two radial slots 3.5 in. long and five deg. wide; see Fig. 3. This disk rotated under a metal plate in which there was a slot the same size as those in the disk and the position of the disk was such that the slot in the plate and a slot in the disk came in line once each cycle. When these slots coincided, the plate of the charged electroscope could draw through some of the ions that arrived at the metal plate, thereby discharging the electroscope. The rate of the discharge of the electroscope is a measure of the relative number of ions arriving at the neutral plane at that instant. The phase angle of the motor driving the disk was changed by means of a phase shifter and in this way the action over a complete cycle could be observed with the electroscope charged positively and then with it charged negatively. The electroscope was charged after each reading by means of a well-insulated switch, S_1. A 1050-kv-a., 60-cycle, sine wave generator was used in this work. To determine the phase position of the synchronous disk with respect to the applied voltage, a contactor C was arranged on the disk so that it closed a circuit at the instant when the slot in the disk and the slot in the plate lined up. With switch No. 2 closed in the A position, a click could be heard in the phones when the contactor closed the circuit. By shifting the phase angle of the revolving disk, a position on the phase shifter could be found where there was no click, which indicated the zero point of the voltage wave. Since the motor used could come into step with the disk in one of two phase positions, 180 deg. apart, it was necessary to be certain that this phase was the same each time the motor was started up. To do this, switch No. 2 was closed in B position and with the phase shifter at the same angle each time the motor was made to come into step so that the d-c. voltmeter read positive.

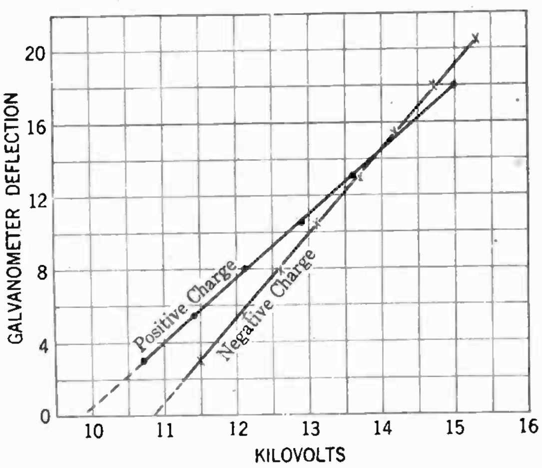

Fig. 2—Curves Showing the Amount of Positive and Negative Charge Arriving at the Neutral Plane in Relation to the Applied Voltage. A No. 14 Polished Copper Wire 5.5 in. from Neutral Plane.

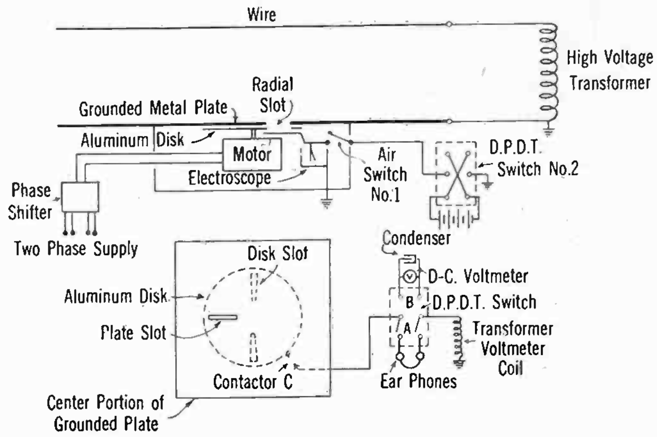

Fig. 3

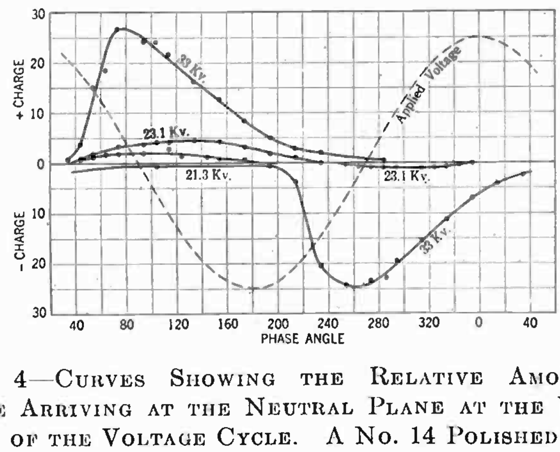

Fig. 4—Curves Showing the Relative Amount of Charge Arriving at the Neutral Plane at the Various Phases of the Voltage Cycle. A No. 14 Polished Copper Wire 5.5 in. from the Neutral Plane

The results obtained by this method are qualitative only but they give additional information that cannot be secured otherwise. Curves shown in Figs. 4, 5 and 6 were obtained by means of this set-up and will be discussed later.

Since the field about a wire above a neutral plane is not symmetrical, it was decided to find out what the

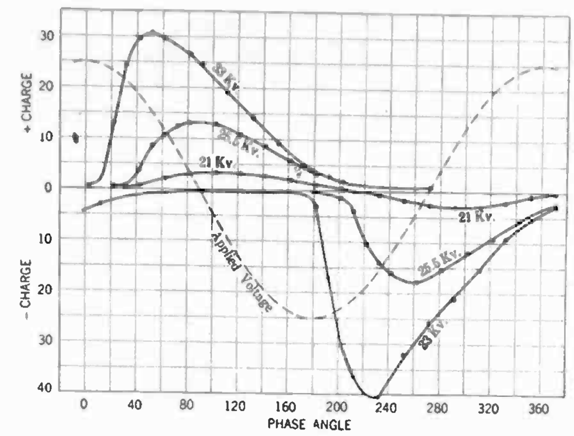

FIG. 5—THE SAME AS FIG. 4 EXCEPT THE WIRE HAD BEEN OUT IN THE WEATHER FOR TWO YEARS WHICH HAD OXIDIZED ITS SURFACE

effect on the form of the curves would be of a uniform radial field. The metal plate was replaced, therefore, by a 15-in. diameter metal cylinder having in it a slot which occupied the same position over the disk as the slot of the metal plate. The data for the curves shown in Figs. 7, 8 and 9 were then taken.

The curves of Figs. 4 to 9 show that, except for magnitude, there is very little difference in the form of the

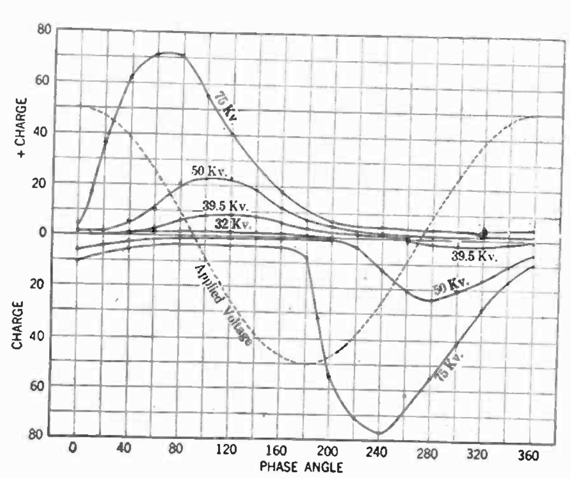

FIG. 6—THE SAME AS FIG. 4 EXCEPT A NO. 10 POLISHED ALUMINUM WIRE WAS USED; ITS DISTANCE FROM THE NEUTRAL PLANE WAS 10 IN.

positive and negative halves of the wave. A very important thing to note is the arrival of the charge at the neutral plane or cylinder sometime after the voltage on the wire has reversed.

There are two fields involved in the drive of the ions across the space, that of the wire itself and that due to the space charge, and the results have shown the latter field to be of considerable importance. In Figs. 4, 5 and 6, the positive charge continues to arrive at the grounded plate even after the voltage on the wire has reversed and reached its negative crest. This is also true for the negative charge and may be attributed to the diffused state of the ions caused by the unsymmetrical field between wire and plane. In the case of the cylinder where the field is radial, there is little or no time when there are ions of both signs present at the

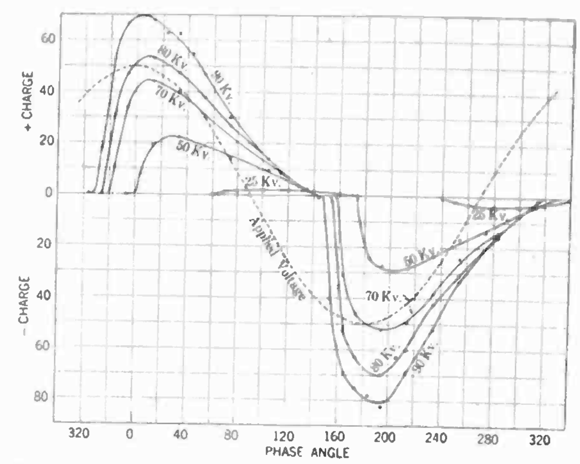

FIG. 7—THE SAME AS IN FIG. 4 EXCEPT FOR A NO. 16 POLISHED COPPER WIRE AT THE CENTER OF A 15-IN. CYLINDER

same instant during the cycle. Figs. 4 and 5 show the difference between a polished wire and one covered with oxide. The positive and negative charges seem to come in at approximately the same voltages with the oxidized wire. An enameled wire was tried also and the curves were similar to those for the oxidized wire. Had a curve been taken at a little higher voltage with the polished wire, the negative charge would have

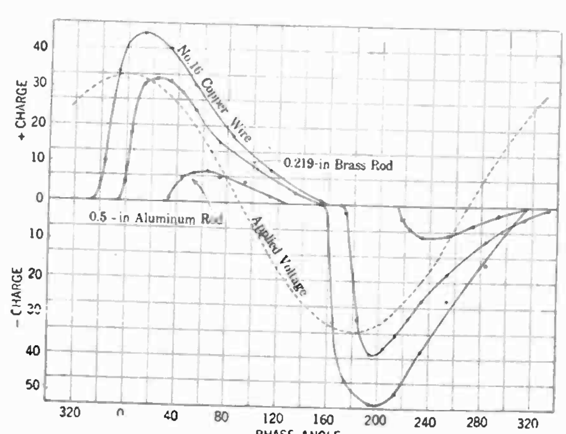

FIG. 8—CONDUCTORS OF DIFFERENT DIAMETERS AT THE CENTER OF A 15-IN. CYLINDER. APPLIED VOLTAGE HELD CONSTANT FOR ALL THREE AT 70 KV.

exceeded the positive as it did in the case shown in Fig. 6.

(Since the scale used for plotting the flow of charge was dependent upon the rate of fall of the leaf of the electroscope, which in turn was dependent upon the position and calibration of the electroscope, the only quantitative comparison of curves that can be made is: Fig. 4 with respect to Fig. 5 and Fig. 7 with respect to Fig. 8.)

It was found that curves obtained with a polished copper wire were practically identical with those secured with a polished aluminum wire of the same size under similar conditions.

In Fig. 9, with the kenotron in the wire circuit, the increase in the flow of charge is to be noted as the voltage on the wire goes over its crest having the same sign as the charge. This increase in the flow of charge is due only to the increase in the field driving the ions across.

Various attempts have been made to compute the movement of ions with conductors in corona. In order to do this, some have assumed varying mobilities for the ions which in our opinion is not justifiable until more data concerning the nature of this space charge are available.

If the distance from the wire to the grounded plane or cylinder be made sufficient, charges of both signs will not get across, but in no case in our tests was the distance so great that none of the charge of either sign got over when corona was present on the conductor.

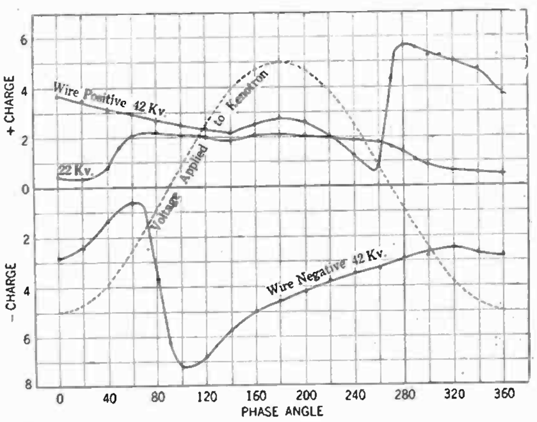

FIG. 9—SAME AS IN FIG. 7 EXCEPT VOLTAGE WAS APPLIED TO THE WIRE THROUGH A KENOTRON

In fact, charges were found 30 ft. out from a conductor of a 220-kv. commercial power line on which there was but slight corona. This test will be discussed more fully later.

For a limited space about a conductor in corona, the sign of the charge is reversed at each reversal of voltage. Beyond this space, charges of only one sign appear, which fact is undoubtedly due to a differential effect of the alternating charge near the conductor. The polarity of this charge is not the same for all conditions. In general, with an unpolished conductor out in the open, such as a transmission cable, the charge is negative at the first appearance of corona but as the voltage is raised it changes over to positive. If the wire is highly polished and near the neutral plane, however, the charge is positive at first and then negative. If the distance to the ground electrode is relatively great, the actual flow of rectified current to supply this outer charge is very small. In some cases, however, the potentials built up by the charges are fairly great.

If in the case of the wire and cylinder some method is used to neutralize or balance out the charging current from the cylinder to ground that would flow if corona were not present, the current that remains is commonly called the corona current. The latter is made up of two elements; namely, the ions that actually reach the cylinder and the bound charge that is drawn to the cylinder by the ions that leave the wire but do not get

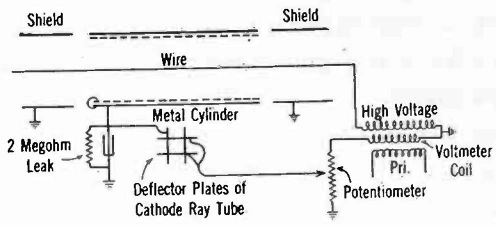

FIG. 10

across. The question arose here as to what percentage of this current was due to the ions that arrived at the cylinder. The set-up in Fig. 10 was used to obtain the corona current. Below the corona starting voltage, a position was found on the potentiometer control such that there was no deflection of the cathode ray. This point, once found, would be the same for all voltages, so that when corona came in, the deflection of the cathode ray would be due to the voltage across the condenser, caused by the corona current only. The value of this voltage was determined from the amount of deflection of the cathode ray, and with the capacitance of the condenser known, the average value of the corona current was computed. The set-up in Fig. 11 was next used to determine the current produced by the ions actually reaching the cylinder. The principle is the same as that shown in Fig. 1. In this case, however, it was necessary to trap all the ions reaching the center section of the cylinder; therefore, a wire cylinder of ¼-in. mesh was fitted inside of the sheet metal cylinder with eighth-in. hard rubber strips separating the two. The main difficulty with this set-up was involved in completely separating the positive and negative ions.

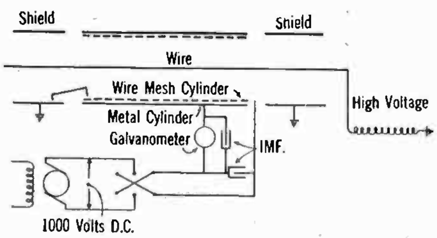

FIG. 11

With the a-c. voltage held constant on the wire, which was in corona, the d-c. voltage applied to the sheet metal cylinder was increased in steps from zero to 1000 volts and galvanometer readings were taken for each voltage. It was hoped that a plot of these values would give a saturation curve indicating a complete separation of the positive and negative ions, but this was not found possible in this case. A wire screen with smaller mesh was also tried but was even less effective. Using the average value of the current, however, as read by means of the galvanometer, when there was 1000-volt direct current on the metal cylinder, it was found in the case of the 0.219-in. brass rod with voltages above 50 kv., at least 70 per cent of the ions that left the wire reached the cylinder before they were drawn back to the wire by the reversal of voltage or were neutralized by the outgoing ions of the opposite sign. With a little modification in this set-up, there is no reason why a complete determination of this ratio could not be made.

Since the corona on a transmission conductor is made up largely, if not entirely, of brushes, a point was placed on the side of the 0.219-in. brass rod in the cylinder and the corona current studied with set-up of Fig. 11. At the first appearance of corona at 11 kv., the charge arriving at the cylinder was negative and remained negative until the positive began to get across at 40 kv. From 40 kv. to 48 kv., there was more positive than negative reaching the cylinder but from 48 kv. up to the flashover voltage the amount of the negative exceeded the positive. The point used was a piece of fine wire 1/16 in. long. The rod was then tried with two such points and it was found that the negative charge arriving at the cylinder always exceeded the positive, although it decreased slightly from 43 kv. to 45 kv.

Space Charge Surrounding Transmission Conductors

The ionization about transmission conductors was next studied. Two concentric strand copper cables 1.1 in. in diameter and 50 ft. long were strung up in the laboratory parallel to each other and 10 ft. apart with a clearance of at least 20 ft. in all directions. A No. 16 wire was supported parallel to, and midway between, the two conductors. Hard rubber rods were used for insulators on this test wire and a lead from it was brought out at right angles to the plane of the two large conductors. An electroscope was connected between the test wire and ground and voltage was then applied to the two conductors. Below the corona voltage, the test wire was adjusted so that the electroscope showed no voltage on it due to position in the electrostatic field which indicated that it was in the neutral plane. The voltage was raised and at the first appearance of corona at 160 kv. between lines the electroscope showed a negative charge on the test wire. The negative potential increased on this wire as the applied voltage was raised until at 280 kv. between lines it was approximately 3000 volts. As the applied voltage was further raised, the potential on this test wire started to fall, slowly at first, then more rapidly, until at 300 kv. between lines it reached zero and then began to build up positive. At 500 kv. between lines the test wire had a positive potential of approximately 15,000 volts above ground. It was necessary to parallel the electroscope with a condenser to obtain the d-c. charge on the test wire when the applied voltage on the conductors was above 300 kv. Another test that was made with this set-up was to short-circuit the electroscope until the voltage had been taken off the large conductors and then the short circuit was removed. When this was done at 280 kv. the test wire accumulated sufficient

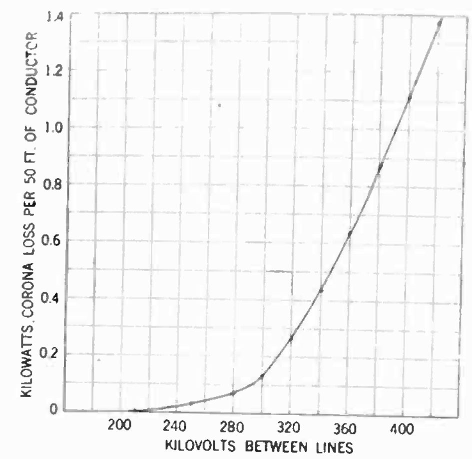

Fig. 12—Corona Loss Curve for a 1.1-In. Concentric Strand Copper Conductor. Distance Between Conductors, 10 ft. Insulator Losses Are Not Included

negative charge to raise potential of the test wire several hundred volts. The same thing was tried at 400 kv. In this case, the potential on the test wire was over a thousand volts positive. These potentials were due to the persistence of the charge about the conductors after the source of ionization had been removed. In some cases, charges were found to build up potentials of a few hundred volts on the test wire as long as fifteen minutes after the voltage had been removed from the conductors.

A corona loss curve was then taken and is shown in Fig. 12. It is rather interesting to note that at 300 kv. between lines there is a break in the loss curve, and it is at this point that the potential of the charge about the conductors changes over from negative to positive.

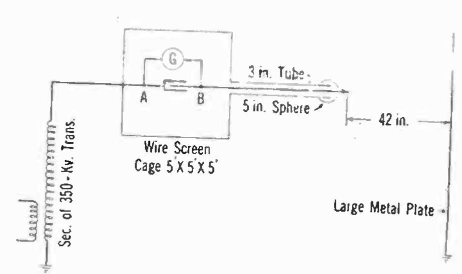

Fig. 13

Above this point, Peek's quadratic law seems to hold, but below, it does not, and it is in this lower region that Peek has suggested a probability law.[6]

Since the corona on these transmission cables appeared to be made up of individual brushes, it was decided to study the characteristics of a single brush. The set-up shown in Fig. 13 was used. An observer in the insulated screen cage at high voltage took all the necessary data. With this arrangement, the capacitance of the metal point is practically zero, so that the only current flow to and from the point is corona current. The simple connection of the condenser and galvanometer was the first one used. At the start of corona from the point which appeared as a soft glow,

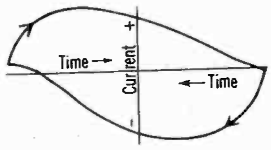

Fig. 14—Corona Current Cyclogram of a Brush from a Single Point. Voltage 100 Kv. 100,000-Ohm Shunt for Current Deflectors and 9400-Ohm Shunt for Timing Voltage

the galvanometer indicated a flow of negative current which increased until at 112 kv. the galvanometer deflection was two divisions. At this voltage, purplish streamers began to shoot out which considerably increased the luminosity of the brush. At 132 kv. the galvanometer had fallen to zero and at 140 kv. the current was positive, giving a deflection of two divisions. By this time the purple streamers had greatly increased and at 172 kv. the discharge was a large, well-developed brush giving a reading on the galvanometer of 10 divisions positive. The condenser and galvanometer were then replaced by the cathode ray tube. A 100,000-ohm resistance connected between the points *A* and *B* gave sufficient voltage drop to obtain a good deflection of the cathode ray that was proportional to the current. This current deflection was opened out into a current cyclogram by applying a sine wave voltage to the other pair of deflector plates. This sine wave voltage was obtained from a 2300-volt exciting winding connected to the high-voltage end of the secondary. This voltage had been tested and found to be a sine wave in phase with the secondary voltage. In order to put the important changes of current intensity in an advantageous position on the cyclogram for analysis, the phase angle of this timing voltage was shifted 90 deg. by means of a condenser. In the cyclograms shown in Figs. 14 and 15, the corona current appears to be a maximum shortly before the timing voltage impressed on the tube is zero, but due to the 90-deg. shift it can be seen that the maximum of the corona current is approximately 25 deg. ahead of the maximum of the voltage applied to the point. The form of these corona cyclograms would be altered slightly if they were changed over to a uniform time axis instead of the sinusoidal timing wave. The direction of rotation of the spot that traced these curves was carefully checked, as was also the polarity of the cathode ray tube deflectors. In Fig. 14, the positive and negative halves of the current wave are smooth and are practically the same. In Fig. 15 the negative side is still smooth but the positive side shows a sudden pulse of current. It was difficult to get the exact form of this pulse because the rapid movement of the spot did not leave a very distinct trace. Simultaneous with the appearance of this pulse of positive current, as the form changed from that shown in Fig. 14 to the one shown in Fig. 15, was the appearance of the long purple streamers. When a half-in. brass sphere was put over the end of the point, breaks appeared in the negative half of the current wave but they were not so prominent as those on the positive side. Time nor space does not permit much more to be said about these tests with the single brush. More work is to be done along these lines and a complete report will no doubt be made later.

Current cyclograms were taken on the 1.1-in. transmission conductor previously mentioned with the charging current balanced out. While they were not so clear cut as those of the brush from the single point, they had the same general form. If all the brushes on the transmission conductor came in at the same voltage, the result, of course, would be practically the same as the brush from the single point except for magnitude. This is very nearly the case when voltage is not far above the corona starting voltage when there are only a few brushes present. Since this is within the economical range, the region we are most interested in, the authors believe that much can be learned about the mechanism of corona about the transmission line by the study of the brush from a single point. It is also their belief that results obtained from polished smooth surface conductors, especially if they are mounted near a neutral plane, are not applicable to transmission lines out in the open.

Tests Made Under a 220-Kv. Transmission Line

In order to tie in the results obtained in the laboratory with those of actual operating conditions, the authors

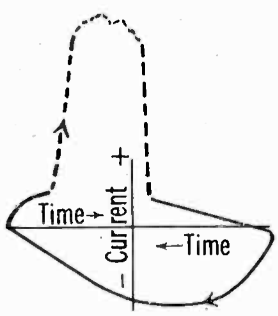

Fig. 15—Same as Fig. 14 Except 130 Kv. and 40,000 Ohms for Current Shunt and 4900 Ohms for Timing Voltage Shunt

went to the 220-kv. lines of the Pacific Gas and Electric Co. at the Vaca-Dixon substation. The section under which the tests were made was that of a three-phase, 220-kv. line with 0.9-in. rope lay copper conductors in the horizontal configuration. The separation of the conductors was about 14 ft. and they were approximately 63 ft. above the ground. At right angles to these conductors and 30 ft. under them, an exploring wire 33 ft. long was supported by hard rubber rods on long cotton cords. A lead was brought down from the exploring wire and connected to one side of a gold leaf electroscope the other side of which was connected to ground. In order to reduce the a-c. voltage due to position, the electroscope was paralleled by a 0.05 μ f. condenser the leakage of which was negligible. At first, a d-c. potential of 400 volts was applied to the wire which at the same time charged the condenser. The d-c. source was then removed and the rate of decrease of voltage on the condenser was observed by the fall of the leaf of the electroscope. With a positive charge on the wire, the voltage of the condenser dropped from 400 to 375 volts in three min. With the wire charged negative, there was no decrease in the condenser voltage for the same length of time. It was obvious then that there were only negative ions present in the vicinity of the exploring wire. This was the condition that was expected to be found in view of the results obtained in the previous laboratory tests. With no charge on the wire, the set-up was left untouched for an hour. At the end of this time the wire had picked up sufficient charge to raise the voltage on the condenser to 305 volts. The charge on the condenser was tested and found to be negative. It was observed that when a rather strong breeze was blowing, the ionization about the wire decreased considerably. This was to be expected with distances from the conductor as great as these.

The voltage was then taken off the section of line above the set-up and the exploring wire was raised until it was within 15 ft. of the conductors. The voltage was then supplied to this section of the line by means of a 40,000-kv-a. synchronous condenser driven by an induction motor. In this way the voltage applied to the line could be varied. Observations were made at three different voltages, 220 kv., 240 kv. and 260 kv. The main purpose of this test was to see if the normal operating voltage was near the value where the residual charge in the atmosphere about the conductor changed from negative to positive. At 260 kv. there was no evidence of any positive charge in the near vicinity of the exploring wire which was 15 ft. from the conductors. The amount of negative charge was found to be slightly greater than it was at 220 kv. with the exploring wire 30 ft. below the conductors.

Acknowledgment

The authors greatly appreciate the generous cooperation of the Pacific Gas and Electric Co. and they are particularly indebted to H. F. Flynn and his assistants at the Vaca-Dixon substation for their invaluable aid in carrying out the test there.

Summary and Conclusions

In the ionization process about a conductor or electrode in corona, there is a net rectifying action present whereby more charges of one sign assert themselves than of the other, so that the surrounding space is built up to a unidirectional potential above ground. Whether it is a case of the charges of the predominating sign being created more rapidly, or whether they endure longer than the others without being "wiped out" by recombination or return to the conducting circuit of the set-up, is not known, as it is apparently a part of the mechanism of ionization involved. It is probably determined by the mobilities of the ions, their rate of manufacture, and the amount that their presence disturbs the normal field.

For a given test arrangement, the magnitude and polarity of this rectified charge is dependent on the applied voltage. For the case of a polished wire and a grounded plane or cylinder, the sign of this charge is first positive, but soon drops to zero and then increases negatively as the voltage is raised. By placing a small "artificial" brush on the wire, it was possible to detect a slight negative rectification at the start of corona from it. The sign soon reversed, though, to positive as the voltage increased, and then to negative once more where it remained until flashover.

In a test with a single point projecting from a small sphere, the rectified space charge built up was first negative and then positive. The same was found to be true in the space between two 1.1-in. diameter cable conductors strung up in the laboratory. This would be expected since the corona on the surfaces of the stranded conductors would be, in reality, a mass of small single brushes, so that as a whole they would assume the characteristics of a single brush.

The fact that at the same voltage on the cable conductors at which the rectification of the charge reversed its polarity from negative to positive, there is a distinct "break" in the corresponding corona loss curve, proved of considerable interest. Since it is at this point that Peek's quadratic law relation begins to hold, it would seem from these tests that there is some governing factor contributed coincident with positive rectification to cause the ionization process to vary quadratically with respect to applied voltage. It is this upper portion of the curve that Dr. Ryan has referred to as that of "stable brush pattern." The lower portion he has called that of "unstable brush pattern," and it is here that Peek has suggested the entrance of a probability relation.

In the field test made on the 220-kv. Pit River Line of the Pacific Gas and Electric Company, which normally shows slight visible and audible signs of corona, it was apparent that the line was being operated at a point well below the "break" in the corona loss curve, as the space about the conductors was found to be charged negatively even when the voltage had been raised 20 per cent above the normal line voltage. Although the potential of the rectified charge is appreciable, the actual magnitude of the current necessary to supply it is negligible compared to the alternating space charge current itself.

Bibliography

3. Whitehead and Inouye, A. I. E. E. TRANS., Vol. 41, 1922, p. 138.

4. C. H. Willis, A. I. E. E. JL., March, 1927, p. 272.

5. Warner and Kunz, University of Illinois, Bulletin No. 114, June, 1919.

6. F. W. Peek, jr., *The Law of Corona and Dielectric Strength of Air—IV*, (Abridged) A. I. E. E. JL., Dec. 1927, p. 1390.

7. Carroll and Ryan, A. I. E. E. TRANS, Vol. 45, 1926, p. 1093.

A NOTE ON THE UNBALANCING FACTOR OF THREE-PHASE SYSTEMS

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In an article appearing in the A. I. E. E. JOURNAL for March 1927, Prof. A. E. Kennelly gave the following analytic expressions for computing the forward (positive-phase or direct sequence) and backward (negative-phase or reverse sequence) components of a dissymmetric three-phase vector triangle.

(A) $$d^2 = \frac{a^2 + b^2 + c^2}{6} + \frac{2\,s}{\sqrt{3}};$$

$$e^2 = \frac{a^2 + b^2 + c^2}{6} - \frac{2\,s}{\sqrt{3}};$$

in which a, b, and c are the lengths of the vectors forming the triangle and s its area; d and e being the magnitudes

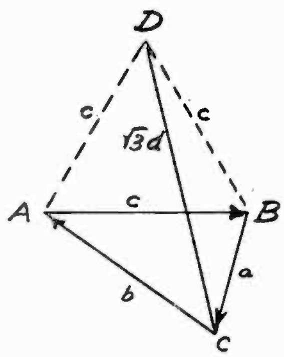

FIG. 1

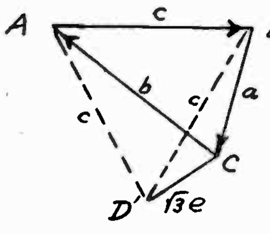

FIG. 2

of the forward and backward components respectively. In deriving expressions (A), he started from the relations—

(B) $$d^2 = \frac{A_m^2 + A_s^2}{2}; \quad e^2 = \frac{A_m^2 - A_s^2}{2}$$

where A_m is the r. m. s. of the sides of the given triangle $A\,B\,C$ and A_s the side length of an equilateral triangle having the same area. Judging from the fact that Prof. Kennelly did not state how (B) could be derived, this must be either self-evident or very simply derivable from his geometrical construction of the forward and backward components. However, the present writer has failed to see this and it will be shown in the following that the relations (A) can be very simply obtained from an alternative method of geometrical construction of the components.

It is well known that the following constructions for the components hold:

Let $A\,B\,C$ be the given vector triangle. Construct an equilateral triangle $A\,B\,D$ externally on the side $A\,B$ as in Fig. 1. Then the magnitude of the forward component is given by $C\,D/\sqrt{3}$. If we construct the triangle $A\,B\,D'$ internally as in Fig. 2, we get $C\,D'/\sqrt{3}$ as the magnitude of the backward component. The lengths $C\,D$ and $C\,D'$ are readily computed. From Fig. 1 by the law of cosines, we have—

$$3\,d^2 = \overline{C\,D}^2 = b^2 + c^2 - 2\,b\,c\cos(60^\circ + \angle\,B\,A\,C)$$

$$= b^2 + c^2 - 2\,b\,c\left[\frac{1}{2}\cos\angle\,B\,A\,C - \frac{\sqrt{3}}{2}\sin\angle\,B\,A\,C\right]$$

As $\frac{1}{2}\,b\,c\sin\angle\,B\,A\,C$ = Area of $\Delta\,B\,A\,C = s$ and

$$2\,b\,c\cos\angle\,B\,A\,C = b^2 + c^2 - a^2,$$

$$3\,d^2 = b^2 + c^2 - \frac{1}{2}(b^2 + c^2 - a^2) + 2\sqrt{3}\,s \text{ or}$$

$$d^2 = \frac{a^2 + b^2 + c^2}{6} + \frac{2\,s}{\sqrt{3}}$$

which is the first equation in (A).

Similarly,

$$3\,e^2 = \overline{C\,D'}^2 = b^2 + c^2 - 2\,b\,c\cos(60^\circ - \angle\,B\,A\,C)$$

$$= b^2 + c^2 - 2\,b\,c\left[\frac{1}{2}\cos\angle\,BAC + \frac{\sqrt{3}}{2}\sin\angle\,BAC\right]$$

$$= b^2 + c^2 - \frac{1}{2}(b^2 + c^2 - a^2) - 2\sqrt{3}\,s$$

$$i.\,e.,\quad e^2 = \frac{a^2 + b^2 + c^2}{6} - \frac{2\,s}{\sqrt{3}},$$

which is the second one of the relations (A).

In passing it should be noted that the constructions herein given do not give the correct phase relation of the components. To get the correct phase relation the line $C\,D$ has to be rotated through an angle 30 deg. counter clockwise and $C\,D'$ through 30 deg. clockwise in order to get the respective positions of the forward and backward components. The unbalancing factor is by definition e/d.

Abridgment of

Lightning Protection for the Oil Industry

BY E. R. SCHAEFFER[1]
Associate, A. I. E. E.

Synopsis.—Building safe storage for the products of the oil industry is quite a different problem from making the storage already in use safe from fires started by lightning. The latter problem is discussed with some principles to be observed. Details of construction are so varied that it is difficult to give general rules. A record of several hundred installations over a period of about three years is given.

Work with small models in the laboratory has been successful in some cases. It is unwise to rely too much on work of this kind, however.

Since the seat of the charge under a storm cloud is largely on pipe lines, tanks, and other metal parts in the oil fields, lightning devices should be securely attached to these structures. A network of pipe lines at or near the surface makes a better ground for towers than a single shaft driven vertically downward to permanent moisture.

* * * * *

Lightning Protection for Oil Storage

Any problem connected with lightning is difficult on account of the magnitude of the quantities involved. Because of the inflammability of hydrocarbons, the complexity of the operations, the great haste, and vast extent of the oil industry, any problem bearing on fire prevention in the petroleum field presents great difficulty. When we associate the two in an attempt to design protection against lightning for the oil industry, the problem is very complex and its solution will not be simple nor easily attained. Any hope of success in such an undertaking must rest on first-hand knowledge of the conditions under which fires most frequently occur, knowledge of details of construction, the varieties of construction used by different companies, special hazards arising from daily operations, and the effects of corrosion.

There are two distinct phases to consider; first, to design an oil tank which will be inherently safe against lightning; and second, to design a system which will offer a high degree of protection for the storage tanks *in actual use* today throughout the oil industry.

The solution of the first is easy and is probably exact. Theory and practise both indicate that the modern all-steel, gas-tight tank is the best type of construction. The solution of the second problem is difficult and at best will result in an approximation, but for the present it is the more important. There are millions of dollars invested in unsafe storage tanks and the aim is to give this property the highest possible degree of protection and at a reasonable cost. It is the purpose of this paper to discuss the design and construction of protective devices for oil storage tanks now in use.

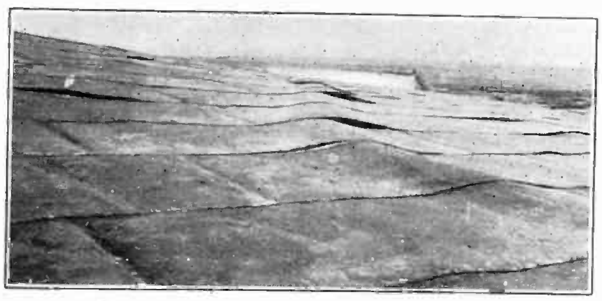

Fig. 1—Showing the Effects on Metal Sheets Nailed to Wood Decks Caused by Temperature Changes and by Filling and Emptying the Tank. In Many Cases the Effects of Corrosion are Just as Bad

Oil is stored in various containers. The most common are steel tanks, spaced on 300-ft. centers, usually about 115 ft. in diameter, 30 ft. high, and having a capacity of 55,000 barrels. Although the tendency is definitely toward the use of steel decks for such tanks, a large number still have wooden roofs or decks, covered with sheets of galvanized iron or vapor-resisting paper and waterproofed fabric. In some localities, corrosion is so bad that steel decks last less than two years and only a wooden deck can be used. This is particularly true where the sulphur content of the crude oil is high. In California and also in the mid-continent field there are a number of earthern reservoirs most of which are lined with reinforced concrete and covered with wood decks similar to those used on tanks. Some of these are circular, having a radius of 250 ft. or more, while others are ovals of radius 300 or 400 ft. and length 600 to 1500 ft. The capacities run from 500,000 to 5,000,000 barrels.

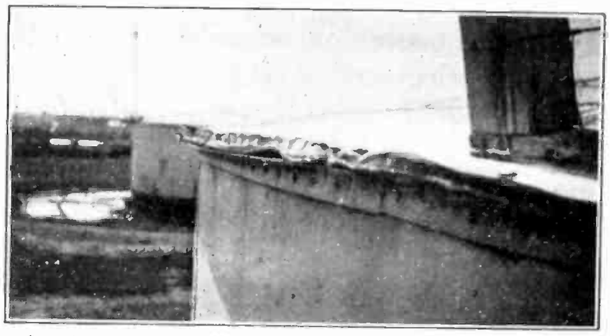

Fig. 2—A Minor Discharge Between the Roofing Material and the Vertical Steel Shell at the Eaves of a Tank which is not Vapor-Tight May be the Cause of a Fire

It is common practise throughout the oil fields to gage and sample the oil from hatches on the deck. There are generally from one to four such gaging hatches per tank and there are several designs with various methods of closing but few of which can be considered gas tight.

If this brief description properly defined the problem,

1. Of the Johns-Manville, Inc., New York, N. Y.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Calif., Sept. 13-16, 1927. Complete copies upon application.

much could be done in an experimental way with models. Unfortunately, however, there is a great mass of detail which seriously complicates the problem. Other tank fittings and arrangements of pipes vary so widely from one company to another than it is necessary to examine the design and installation of each company, and frequently of each tank, for appliances which are liable to give rise to sparks during electrical storms. Special hazards introduced by the location and character of structures near oil storage complicate the problem still further and discount any scheme of protection which is based entirely on the behavior of models of isolated miniature tanks and devices in the laboratory.

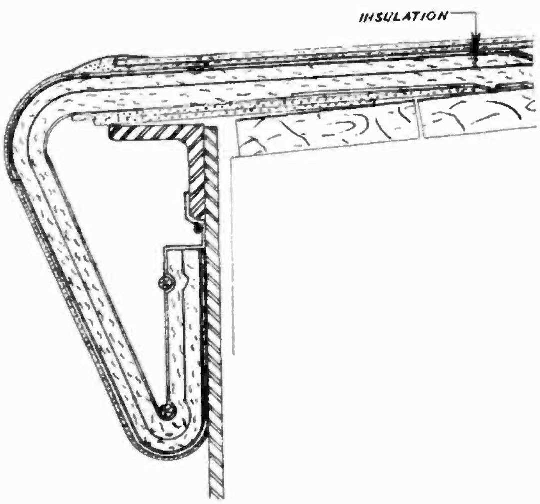

Fig. 3—Cross-Section of the Eaves Construction which is Flexible and Vapor Tight. It is Composed of Heat Insulation, Usually Hair Felt, and Roofing Fabrics

While the main lightning discharge is so powerful that it is liable to cause fires under any conditions, it is not necessary that an oil container receive a direct lightning discharge in order to cause a fire. Some years ago when little or no precaution was taken in the refineries against escaping gases, it was not uncommon to have a number of fires resulting from a single lightning flash in the vicinity of the refinery. Under such conditions, only a small spark is necessary to cause a fire, and it is well known that such sparks due to the surge of electric quantity across the earth's surface or to induction have caused fires at a considerable distance from the point which received the main discharge from the cloud. To illustrate, one large company erected a tower about 120 ft. high in one of its tank farms. A few weeks later the tower was struck and two tanks were fired, one tank about 200 ft. away and the other tank about 900 ft. from the tower. The disastrous fire at Monterey, California in 1924 was caused by lightning setting fire to a tank when the main discharge was received by a tree 780 ft. away. The reservoir fire at Coalinga in 1924 was caused by lightning although the actual flash was seen to strike on or near a pipe line about a quarter of a mile from the reservoir. The great reservoir fires at San Luis Obispo and at Brea, California in April 1926 were unquestionably caused by lightning. It is not known whether the latter fires were caused by direct hits or by minor sparks which accompanied the lightning discharge. The reservoir fire at Bakersfield a few weeks later was reported to have been caused by a direct strike of lightning which tore a hole in the deck. This reservoir was a simple earthern pit without reinforced concrete lining and it contained fuel oil.

It is impossible to say what percentage of oil fires have been caused by direct hits and what percentage by small sparks or secondary effects, but from the available data, it is reasonable to conclude that a large majority was caused by secondary lightning discharges.

Evidently, in the daily handling of large quantities of inflammable material and in the storage of such material in containers that are not actually gas tight, there is great danger that small sparks, which always accompany lightning discharges, may cause a fire even though the main discharge be several thousand feet away. Sparks caused by the surge over surfaces of varying resistance or along several paths of different impedance, when the earth's charge disappears at the instant of a lightning flash, are most certainly the cause of a majority of the fires and explosions in the oil fields.

In a general way, there are three conditions to fulfill for the prevention of fires on oil property set by minor discharges:

1. With the exception of one breathing vent, the containers must be kept closed,

2. Isolated pieces of metal in or near the vapor space must be grounded and all loose joints between metal parts must be eliminated to prevent the possibility of sparks,

3. The vulnerable areas should be enclosed by a Faraday cage or network, completely enclosing the non-metallic parts and securely grounded.

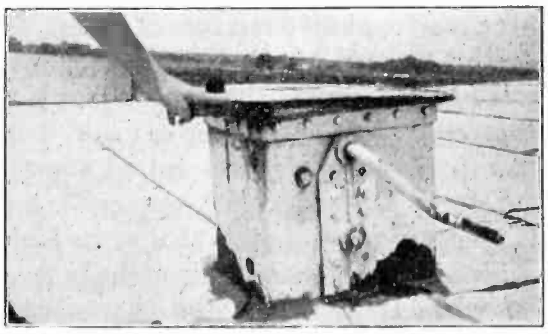

Fig. 4—A Winch Box on the Deck. The Cover is not Vapor Tight

When it is realized that all this must be done at small cost, without cleaning the tanks, and frequently when the tanks are filled with oil, the magnitude of the problem is apparent.

The design and construction of a suitable network or cage is the most important thing to be discussed here. Such a network was first designed and applied to wooden roofed tanks which had been covered with heat insulation and had been made vapor tight with flexible materials to prevent evaporation losses.

If a network of wires is placed under the heat insulation and roofing material, the wires would have to be very close together to prevent sparks between and below the plane of the wires, in or near the metallic fittings on the deck. There is danger also that when under storm conditions the charge on the deck is suddenly released by a lightning discharge, the roofing material may be punctured. This is particularly likely to happen at the edges of tank fittings or at the eaves where shallow pools of water may collect directly

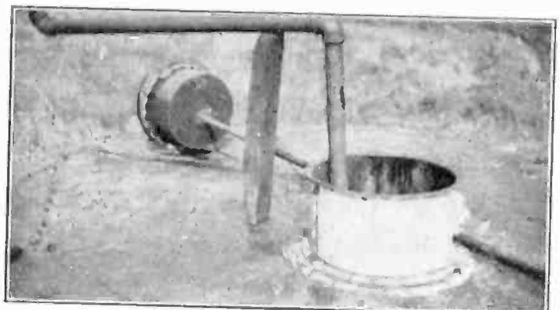

FIG. 5—AN OVER-SHOT FILLING PIPE PASSING THROUGH A LARGE HATCH ON THE DECK

over the angle irons of the tank. If some material such as poultry netting is used there is great danger of sparks at the mechanical junctions where the netting is attached to the tank and at the edges of the strips of netting since all junctions must be purely mechanical. If a network of small mesh wire is placed directly over the roof and resting on it, there is the same danger of sparks occurring and, in addition, it would be again particularly difficult to deal with tank fittings where gases escape during changes of temperature of the vapor space or during the time the tank is being filled. Since only mechanical junctions are permissible, and these are very likely to spark during high-potential discharges, it is important that such junctions are not in a region where there is an explosive mixture of gases.

This factor, as well as the high cost of installing a network of small mesh and the danger that it would be damaged by workmen on the tank, made it necessary to consider a network of wires raised some distance above the deck. If wires were stretched across the deck it is necessary first of all that they be high enough so men can work under them. Since the purpose of the system of wires is to reduce the charge which may collect on the deck under storm conditions, and to provide a low-resistance path to ground when a lightning discharge occurs, the network must be grounded in a satisfactory manner. It should be securely attached to the tank itself and additional precaution should be taken to protect the eaves of the tank, since it is well known that most of the fires start there. The most obvious design then was a system of wires extending radially from a central wooden post at the peak of the deck to a cable supported above the eaves. This cable would have to be about 7 ft. above the eaves and supported preferably by metallic members attached to the tank as securely as possible without welding. It was necessary then to determine how far apart such wires should be and, if possible, to measure the degree of protection that such a distribution of conductors would offer, or at least find the ratio of the charge on the elevated conductors to the charge on the tank roof when a charged cloud was overhead.

Preliminary tests were made on a wooden platform about 12 by 20 ft. covered with hair felt and saturated paper similar to the construction for vapor tight tank roofs. This deck was set up 2 ft. above the floor in a large room with a system of four parallel No. 4 copper wires arranged 6½ ft. above the deck. The spacing of these parallel conductors was varied during the course of the experiments from a few feet up to the entire length of the deck. Above these parallel wires was a cloud of poultry netting, 10 by 24 ft. suspended from the ceiling by cotton tape. This netting was connected to one terminal of a large transformer; the other terminal was connected to the parallel wires over the deck. At one edge of the roofing platform, this grid was dropped vertically downward to the deck and grounded. The surface resistivity of the saturated paper on the deck was quite high when the surface was dry, being about 100,000 ohms per cm. This was reduced by a large factor when the paper was wet.

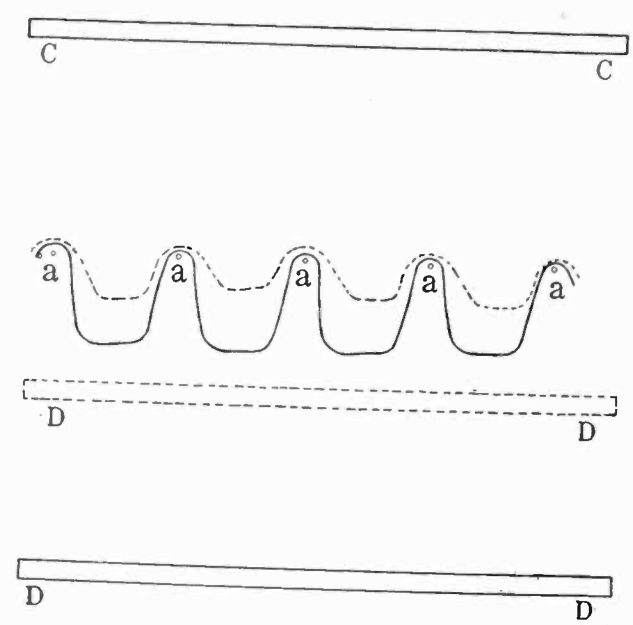

FIG. 6—EQUIPOTENTIAL LINES IN THE CURRENT SHEET. THE FRACTION OF THE CURRENT WHICH FLOWED TO THE GRID (*a a a*) INDICATES THE AMOUNT OF SCREENING PRODUCED BY THE GRID IN THE ELECTROSTATIC CASE

A number of methods were tried for determining the potentials at points in the field between the deck and the poultry netting, particular attention being given to the region between the deck and the plane of the grid. None of the methods tried was considered satisfactory. However, equipotential surfaces were plotted and it was estimated, from the shape of these equipotential surfaces, that the amount of protection given was about 75 per cent.

The equipotential lines in a current sheet can be easily studied and this gives a simple method for getting the required information. Accordingly, apparatus was set up to represent the cloud, a parallel grid and the earth in cross-section and the work carried out in a small horizontal glass tray. Referring to Fig. 6 *C C* is the cloud, *D D* the deck or plane to be protected and *a a a* is the grid; that is, the points of intersection of the wires with the vertical plane perpendicular to the wires. The tray had a plate glass bottom about 24 by 36 cm. and contained dilute salt solution to a depth of about 0.3 cm. The cloud (*C C*) was a bar of brass and formed one terminal for the current sheet in the tray. The protecting wires (*a a a*) were small pointed brass rods screwed into a horizontal bar supported above the water. These rods were all adjusted in length so that they just touched the glass tray. The bar holding these rods was connected to the bar (*D D*) representing the deck and these together formed the other terminal. Using low voltage, 500 cycles, equipotential lines as shown in Fig. 6 were obtained by using a telephone receiver and exploring points.

When *D D* was moved downward to the new position *D' D'* the equipotential surface dropped down as indicated in the figure. In order to get some idea of the screening action of the grid, the bar holding the points (*a a a*) was disconnected from *D D* and the currents which flowed from *C C* to the grid and to the deck (*D D*) were measured. These currents were measured for a number of different positions of the cloud *C C* and of the deck. Also the spacings of the points *a a a* were changed. The ratio of the current flowing to *a a a* and to *D D* was taken to be the value of the protection offered to the plane *D D* by the wires (*a a a*). This ratio was practically independent of the position of *C C* so long as *C C* was more than three times the spacing of *a a a*. It depended very much, however, upon the spacing between the wires (*a a a*) and the distance from these wires to the plane (*D D*). So long as the bar (*C C*) was some distance away from the grid the ratio of the spacing of the grid to the elevation above *D D* determined the amount of protection.

Maxwell calculated the screening effect of a grating of equally spaced parallel wires on a plane surface parallel to the grating. This is the simplest case and is probably the only one that has been solved mathematically. The formula derived by Maxwell[2] gives the density of charge induced on the lower plane when the grating is interposed. The density of this charge is to that induced if the grating were removed as

$$1 : 1 + \frac{b_1 b_2}{\alpha (b_1 + b_2)}.$$

where b_1 is the distance from the grating to the lower plane, b_2 the distance from the grating to the upper plane and α is a function of the spacing of the wires given by the following expression:

2. "Electricity and Magnetism," Volume I, Article 203.

$$\alpha = -\frac{a}{2\pi} \log\left(2 \sin \frac{\pi c}{a}\right)$$

Spacing of wires	Height of wires	Calculated protection
3 ft.	7 ft.	86 per cent
5 ft.	7 ft.	75 per cent
7 ft.	7 ft.	66 per cent
3 ft.	10 ft.	90 per cent
5 ft.	10 ft.	81 per cent
7 ft.	10 ft.	73 per cent
10 ft.	10 ft.	65 per cent

A large number of readings were made then with the current sheet to get values indicated for the protection offered by a grid. The percentages were all from 1 to 6 per cent higher than those calculated. While the experimental method is probably not capable of great accuracy, it did indicate a procedure for studying cases which are too complicated for mathematical solution.

The experiment with the current sheet is so simple and the results obtained were apparently so satisfactory

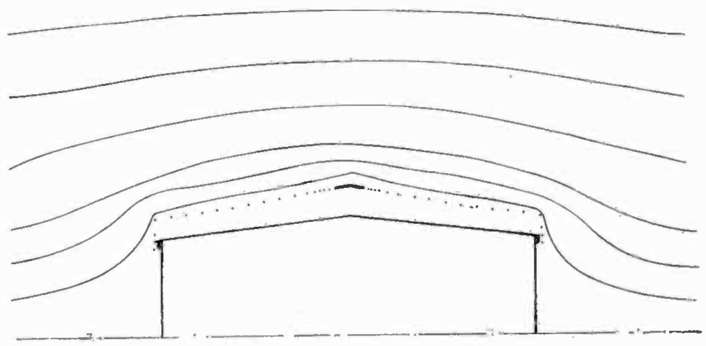

Fig. 7—Cross-Section of a Tank Protected by a System of Parallel Wires 7 Ft. or More Above the Deck. The Actual Model in Use was 2 Per Cent of the Diameter of a 55,000 Barrel Tank

that it was decided to study the cross-sections of details on a much larger scale. A large piece of plate glass 40 by 60 in. was used as a tray. A cross-section of a storage tank was inserted at the base of the tray over which was arranged a cross-section of the proposed network. The currents flowing to the cross-section of the deck and to the grid were again measured. In this case, the deck was receiving 13 per cent of the total current.

The records of tank fires show that in a large majority of cases, the fires start at the eaves of the tank. Accordingly, a large model of the eaves construction was made and the proposed plan for the grid installed in cross-section. Fig. 8 shows the reproduction of the equipotential lines traced for the eaves construction. It was not found possible with this arrangement to trace equipotential lines under the grid when the wires are placed very close together on the vertical bracket (*v v*). This model was made to scale, on the supposition that the cable at the top of the bracket was to be installed 7 ft. above the eaves and extend outward beyond the eaves, about 3 ft. It is evident that a network must not only cover the deck but it must enclose it. While a fairly large spacing of the wires is probably satisfactory over the deck, the region over and around the eaves should be protected with a wire net of small mesh.

Since an actual installation gives a cage which is much more effective than a system of parallel wires,

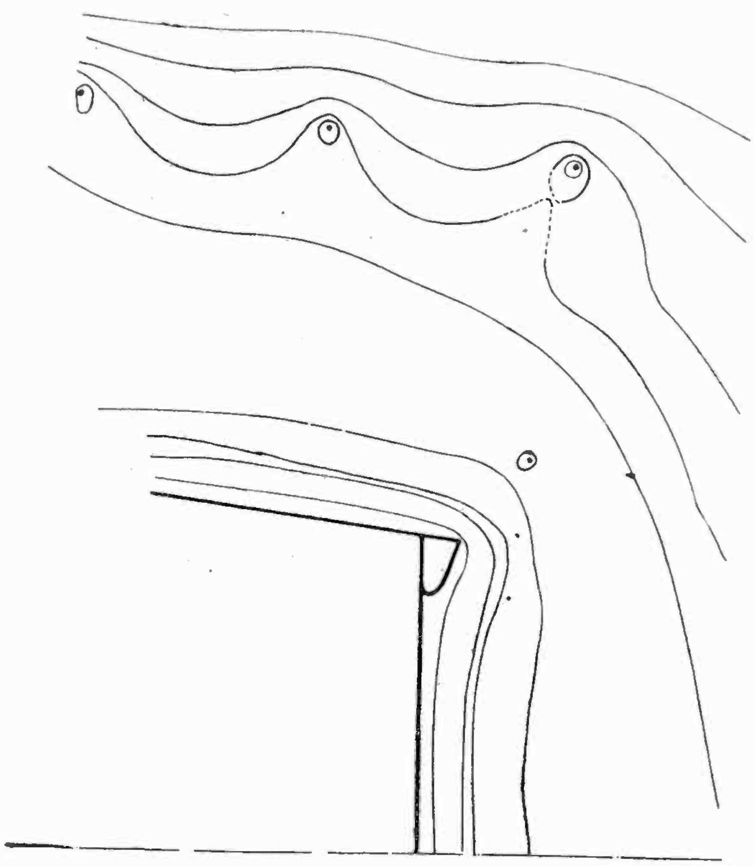

FIG. 8—EQUIPOTENTIAL LINES AT THE EAVES OF A TANK PROTECTED BY A SYSTEM OF WIRES. THE PROTECTION IS INCREASED BY PLACING WIRES CLOSE TOGETHER ON THE VERTICAL BRACKET *v v*

which this last model represented, it was necessary to build a model and devise a method for getting the effectiveness of a miniature network. So a tank model was made to be tested for the three-dimensional case. The tank was built of a wooden frame on the scale of 1 to 40 for the 55,000 barrel tank. Galvanized iron was used for the tank and a system of radial wires applied to scale according to the proposed scheme. The cloud consisted of one-in. mesh wire screening, 5 ft. by 10 ft. A vibration galvanometer was used merely as a sensitive a-c. ammeter to measure the charging current to the capacities formed by the network and the roof. Charging currents are proportional respectively to the capacities and to the charges that collect on the network and the roof. The results obtained this way were checked by using a ballistic galvanometer for comparing capacities. The ratio of the deflections gives directly the ratio of the charges desired. Measurements with the vibration galvanometer gave 96.8 per cent of the charge on the network. The ballistic galvanometer gave 98.4. This is the ratio of the charge which collects on the shell of the tank mode and the network to the charge which collects on the insulated metal tank top under the network.

Some tests in the field have been made to get an approximate idea of the efficiency of this network as actually installed on a tank. The attempts to measure the effect directly indicate that the efficiency is greater than 90 per cent. A more accurate result cannot be given on account of the difficulty of measurement and the crudeness of the apparatus used. The method consisted in measuring simultaneously the quantities of electricity discharged, at the time of the lightning flash, from a section of the network itself and similar conductors protected by the network. An improvement of this method will in all probability yield valuable information concerning the size of mesh necessary to reduce secondary effects to an even greater safety.

The ratio of the spacing of the radial wires composing the network to the elevation above the deck has a maximum value of five to seven over surfaces which are poor electrical conductors. The minimum value of the spacing was 18 in. at the eaves. Certainly this spacing of wires is too great unless conditions are very favorable. It is of the greatest importance to eliminate poorly

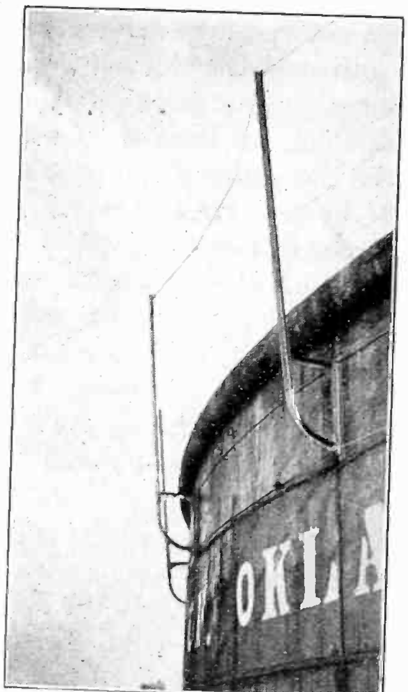

FIG. 9—DOUBLE ANGLE-IRON BRACKETS ON THE TOP RING OF THE TANKS HOLD THE PERIPHERAL CABLE TO WHICH THE RADIAL WIRES ARE ATTACHED

connected or isolated pieces of metal wherever possible. When this is not possible, it is necessary to use a screen of small mesh. The smaller the mesh the more complete the protection but the smaller the mesh the greater the cost and in most cases the greater the difficulty of application. Since most fires start at the eaves of the tanks it is advisable to increase the protection at this point. While the spacing of wires over the tank proper may be satisfactory the spacing in the vicinity of the eaves should not be greater than 1 ft. Welded mesh wire with a 4-in. spacing should be installed on the steel brackets. This mesh wire should be 6 ft. wide and should extend completely around the tank at the eaves. The lower edge of this mesh should be at least one ft. below level of the angle iron on top of the tank shell. Above this width of welded mesh, No. 12 wires should be installed one ft. apart on the brackets and on the radial wires over the eaves.

If economy were not an important consideration many special problems and difficulties could be avoided by using a network of sufficiently small mesh. A grid of wires may reduce effects to a very small fraction but this may not be enough if the structure to be protected is fundamentally bad, or when operating conditions are such that fires may be easily started. A large quantity of gas is given out when crude oil is pumped into a tank and a lightning discharge near the tank at this time is very dangerous regardless of the protective devices. When oil is pumped out of a tank the air entering makes an explosive mixture and a very small spark will destroy the tank.

The over-shot pipe which passes through an open hatch is still in daily use in some places and may occasionally be used in emergencies by the most careful oil men. A surge along this pipe line is likely to cause a spark where the pipe passes through the tank roof and of course such a spark would ignite any vapors present.

In most cases the breathing vent is installed on the deck. These vents, fitted with fine mesh screens, are usually low but in some cases extend 5 ft. or 6 ft. above the deck, and, in one case, over 20 ft. This extension was made so that if the vapors catch fire the flames will be high enough above the deck to prevent setting fire to the roofing materials. Probably the most satisfactory solution here is to avoid anything over 4 ft. high and to install a net of 2-in. mesh wire on top of the grid composing the main network.

A large number of special problems have been considered during the past three years. Much experimental work has been done with models of tanks, of reservoirs, of gas collecting systems, and other construction details, using various types of electrical discharges. In some cases the results of work seemed to be definite and conclusive but in the majority of cases such experiments were unsatisfactory. Several investigators have made use of small models and unquestionably much of value has been learned in this way. However, one thing brought out very clearly during the course of this study was that the greatest care must be exercised in the interpretation of results in laboratory tests on models. It is quite possible to make a device or small model and apparently prove it satisfactory when experience under actual conditions shows it is not. Even though the models, cloud elevations, and voltage are reduced to a convenient scale, there are some factors which cannot be so reduced and, what is just as important, there are always conditions in actual practise which are quite impossible to simulate. Unfortunately, it takes several years to accumulate information in the field which could be obtained in a few weeks in the laboratory. But if the field record is from a large number of applications and the time includes sufficient number of severe storms the information is, of course, of prime value.

The network essentially as previously described has been installed on about 800 tanks during the past three years. These tanks are well distributed from Pennsylvania and New York, through Louisiana, Texas, Oklahoma, Kansas to California. The first and the largest number of installations was made in the mid-continent fields where the damages from lightning in the past have been very heavy. In a group where there are over 100 protected tanks, one tank was fired by lightning just two years ago. There have been no losses in this group since. In an equal period of time, including nearly the same number of storms, prior to

Fig. 10—Water Seal for the Eaves of a Large Reservoir in Course of Construction. The Trough is Concrete Reinforced with Welded Mesh Wire. Sheets of Zinc are Nailed to the Deck and Bent Downward into the Trough. The Wood Deck is then Covered with Roofing Paper

the installation of the networks, nine tanks in this group were fired by lightning.

Several other fires have occurred on protected tanks, but always on tanks which, on account of operating conditions, were particularly susceptible, and which could not properly be considered to have a fair degree of protection. In two cases the hatches were open and the tanks were being filled with Oklahoma crude when the tanks received a direct lightning discharge. In two other cases the heat insulation and vapor tight roof had been installed over loose metal sheets. The oil had just been pumped out of these tanks leaving a mixture which exploded when struck by lightning, blowing the entire roof off the tanks. It is too much to expect a simple inexpensive network to protect tanks containing explosive mixtures and so constructed that there are numerous air-gaps between disconnected pieces of metal. Only one fire has occurred with conditions under which the network should have been effective.

In all other cases, the fires were due to changing conditions during the process of normal operation of moving the oil or due to causes otherwise avoidable. Eliminating those cases where for some reason the tanks were open, the reduction in the number of fires for a period of two and a half years amounts to over 90 per cent.

It is definitely known that some of these fires were started by primary discharges and it is probable that all were started in this way. Certainly some of the fires could have been prevented if towers had been used to protect the tanks from direct lightning discharges although in several cases recently reported, no fire was started when a direct lightning discharge was received by the network.

The large ground reservoirs presented new difficulties, but the enormous value concentrated into a relatively small space, justified greater expense in building a protective system. The cooperation of several of the California companies in working out details of construction, and their excellent scheme for reducing the oxygen content in the vapor space of the large reservoirs, by

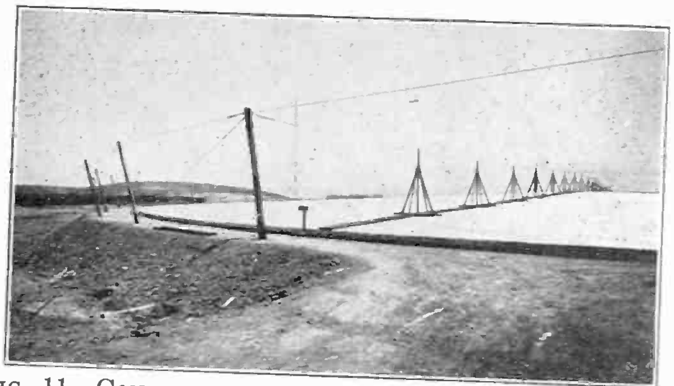

FIG. 11—CONSTRUCTION ON THE EMBANKMENT OF A LARGE RESERVOIR SHOWING THE PERIPHERAL CABLE, GRID AND, IN THE BACKGROUND, A STEEL TOWER

the introduction of flue gases, made possible a degree of protection of the highest order.

A million and a half barrels of oil may be stored under one roof, half underground, on about 10 acres which otherwise would require 30 tanks on at least 50 acres. These reservoirs usually have a lining of concrete reinforced with 6 by 6-in. welded mesh wire No. 6. The mesh is 10 ft. wide, lapped 6 in. on each strip and fastened together with short pieces of soft wire. This mesh wire is carried up to the eaves and is covered with concrete. The bottom of the reservoir usually contains several in. of water and above this the depths of oil may be as much as 30 ft. A number of pipe lines may lead into this reservoir, the main lines being usually 16- or 18-in. pipe. Surrounding the reservoir there is usually a three of four in. water line with fire hydrants, 300 or 400 ft. apart. Such pipe lines form the best means for grounding lightning devices.

The record of some appliances which have been in use for a number of years suggested that a peripheral cable grounded at frequent intervals is probably the most satisfactory and economical protection for the eaves of the ground reservoirs. If this is supplemented by a number of steel towers arranged around the reservoir, a high degree of protection should be obtained against primary lightning discharges. A grid of wires over, the entire deck would raise the charge under a storm cloud, above the deck and provide a path for the surge which otherwise would go over the deck when the cloud discharged.

Accordingly, telegraph poles were installed 40 ft. apart on the top of the embankment of the reservoirs about 12 ft. out from the eaves. These poles are 12 ft. above ground and are listed about 2 ft. outward from the reservoir. A 3/8-in. stranded steel cable is supported near the top of these poles and extends completely around the reservoir. One or more guy wires, extending from each pole, are connected to this peripheral cable the guy wires serving the double purpose of mechanically strengthening the system and affording good grounding connection. These grounds consist of metallic screw anchors and are all connected together by an underground copper cable which, in turn, is grounded to all of the pipe lines in the vicinity of the reservoir.

A detail map of an area that has been developed by an oil company shows a maze of pipe lines of many sizes, steel tanks, ground reservoirs and, in many cases, stills and steel towers if the storage is near a refinery. Evidently the charge on the earth under a storm cloud is distributed over these conductors and, when the cloud is discharged, surges travel along pipe lines and over wet ground toward the point where the lightning strikes. If this view is correct, towers, cables, and grids should be securely attached to tanks and to pipe lines on or near the surface. When a tower in this area receives a lightning discharge the charge on the earth's surface would collect principally on pipe lines and travel in a surge toward the tower.

A number of simple resistance measurements were made in the oil fields of Oklahoma, Texas, Louisiana and a number of places in California which indicated that the pipe lines were quite satisfactory for grounding lightning devices. In several locations resistance measurements were taken on the casing of water wells from 50 to 300 ft. deep. From these points it was established that pipe lines were well grounded and from the latter a number of tanks were found to make good contact with the earth. Although several hundred measurements have been made, in no case has it been found that the resistance of a pipe line to ground, or of a steel tank amounted to more than half an ohm.

It is sometimes considered necessary to sink a shaft 50 ft. or more, to permanent water, to establish a good ground for lightning towers. Surely this can do no harm, but it is doubtful if there is information which indicates that it is necessary.

Abridgment of

Characteristics of Interconnected Power Systems
As Affected by Transformer Ratio Control

BY L. F. BLUME[1]

Associate, A. I. E. E.

Synopsis.—*Operating characteristics of interconnected systems in which voltage is maintained constant by varying field of the generators is compared with operating characteristics, when, in addition to the control of generator field, transformers equipped with ratio control are employed. The use of transformers with variable ratio introduces a flexibility in operation which permits the division of wattless currents between generating stations independent of voltage held at the generator busses.*

A comparison is made of the use of synchronous condensers for the purpose of improving regulation as compared with the use of transformers equipped with ratio control.

The elementary conditions which govern the current distribution in a loop, L, are determined in terms of impedance characteristics of the net-work. The equipment necessary to control the current distribution and at the same time maintain good regulation in the loop are indicated.

THE steady and rapid growth of the use of variable ratio transformers in connection with interconnected central stations makes it of interest to state the fundamental characteristics of apparatus in systems which make these equipments desirable. In a paper[2] before the Institute two years ago, Mr. Albrecht indicated their field and compared their characteristics with induction regulators and synchronous condensers. The purpose of the present paper is to focus attention on a few of these characteristics in order to indicate how quantitative values may be obtained.

The various kinds of voltage control now being used on power systems are:

1. Voltage control by means of generator field current,
2. Synchronous condensers or phase modifiers by means of which the power factor in transmission lines is improved and thus better regulation obtained,
3. Voltage ratio control, either by means of transformers or induction regulators.

The above methods of voltage control will be considered in connection with specific, typical cases, although in the most practical instances it is admitted that the problem is more complicated than the assumptions of this paper imply. The principles as outlined here, however, are applicable, with proper modifications, to the more complicated ones. The four typical cases to be discussed are:

1. Where two generating systems are connected by means of transmission line and power may flow in either direction,
2. Where two generating systems are connected by means of transmission line but one-way flow of power only is required,
3. A generating system with a synchronous condenser floating on the end of the line,
4. Transmission line loop.

1. Transformer Engineering Dept., General Electric Co., Schenectady, N. Y.

2. H. C. Albrecht, *Transformer Tap Changing Under Load*, A. I. E. E. TRANS., Vol. 44, 1925, p. 581.

Presented at the Regional Meeting of District No. 1 of the A. I. E. E., Pittsfield, Mass., May 25-28, 1927. Complete copies upon request.

CASE I: TWO-WAY FLOW OF POWER OVER TRANSMISSION LINE CONNECTING TWO STATIONS

With two central stations connected together by means of an interconnecting transmission line (Fig. 1) the operation of the system involves the control of:

1. The division of energy between the two stations,
2. The division of wattless kilovolt-amperes,
3. The voltage at the two busses.

The controls available are (a) throttle control, (b) field control, (c) voltage ratio control. It is evident that the division of energy between the two stations is not determined by the electrical characteristics but by the characteristics of the prime mover and the throttle control. Field control at the two stations does not affect the energy flow, but determines for each load demand the voltages on the two busses, together with the division of reactive kilovolt-ampere between the stations. But field control cannot independently determine the bus voltages and division of reactive kilovolt-ampere. Either can be controlled, but not both simultaneously; thus the field control may be used to hold the bus voltages equal and constant for all loads, under which condition the division of reactive kilovolt-ampere between the stations is determinable but uncontrollable. Conversely, by means of field adjustments it is possible to control the division of reactive kilovolt-ampere between the stations or what amounts to the same thing, the power factor in the line, but when this is done, voltage control on the two busses is sacrificed. The voltage of one point on the system may be held constant, but the other bus voltage will vary through a range which is equal to the regulation drop between the two busses.

In order to control, independently of each other, the three characteristics, namely, *energy* division, *reactive* kilovolt-ampere division, and *voltage* at both busses, it is necessary to introduce a third independent control. This is readily accomplished by introducing variable voltage ratio between the two busses variable under load.

Thus, by means of the insertion of variable ratio between the two busses, it becomes possible to maintain both bus voltages constant at all loads, which means that the regulation drop between the two busses is zero, and at the same time, to obtain any desired division of current between the two stations. With the flexibility of operation thus obtained, the bus voltage of the two stations may be maintained constant, and at the same time the division of current between stations may be adjusted so as to obtain either

A. Maximum electrical efficiency,

B. Maximum economy in operation,

C. Maximum utilization of apparatus.

Although all three of the above are desirable aims, it is rarely possible to obtain them simultaneously. For example operating for maximum electrical efficiency is simultaneous with operation for maximum economy only when the cost of energy delivered by station A to the load is equal to the cost of energy delivered by station B to the load. With equal energy cost, the division of current to obtain maximum efficiency depends entirely upon the relative losses in the two branches.

When the cost of energy in branch A and branch B, including the transmission line, differ materially, maximum economy is secured by shifting a portion of the load kilowatts from the station in which the cost of energy is greatest to the other station. This results in a reduction in efficiency but an increase in economy. As the division of reactive kilovolt-ampere for maximum economy is not affected to as great an extent by cost of energy, the currents flowing in the two branches for maximum economy are no longer in phase with the load.

Division of current, to obtain maximum economy in operation, is the desirable operating condition for fractional loads but when the total load demand is equal to, or approaches the full kilovolt-ampere of the system, the rating limitations of the apparatus and line may demand considerable departures from division of currents as determined by the consideration of maximum economy. In order to deliver a maximum output, the division of current must be such as to obtain the maximum utilization of the apparatus.

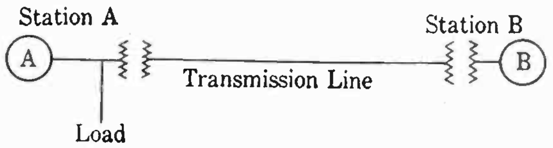

FIG. 1—ELEMENTARY DIAGRAM OF INTERCONNECTED SYSTEMS

It is a relatively simple matter to obtain a measure of the extent to which the use of ratio control increases the maximum load which a given system can deliver to a given point without sacrificing constant voltage at the two busses. This may be done by determining quantitatively the limitation which exists when the system is operated in which only throttle and generator field control are employed.

Voltage Relations. We shall assume that the load to be delivered may be concentrated on either bus of the two stations A and B, Fig. 1, and that it is desired to maintain voltages of busses A and B constant and independent of the load demand.

Assuming that the flow of power will sometimes be in one direction and sometimes reversed, the regulation drop in the transmission line and interconnecting transformers should be zero. Therefore, equating

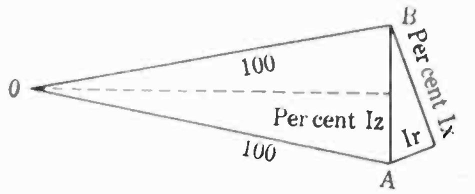

FIG. 2—VOLTAGE RELATIONS IN INTERCONNECTED SYSTEMS
$O\ A$—Equals voltage of bus near load,
$O\ B$—Equals voltage of bus far from load,
θ —Equals phase angle of current in transmission Line

the expression for regulation to zero, we have approximately:

$$(\%\ I\ R)\cos\theta - (\%\ I\ R)\sin\theta = O$$

from which

$$\tan\theta = \frac{\%\ I\ R}{\%\ I\ R} \qquad (1)$$

From this formula it is evident that the maintenance of the two busses at constant voltage at all loads involves the operation of the transmission line at a leading power factor $\cos\theta$ the value of which is determined from the ratio of resistance and reactance of the line.

A more exact solution can be obtained graphically by plotting the vector diagram of the transmission line voltages, Fig. 2. The premises of the problem make the three voltages an isosceles triangle $O\ A\ B$ in which the impedance drop of the line is the base $A\ B$ and the sides are the bus voltages of the two stations. From this diagram we may write:

$$\sin\alpha = \frac{\%\ I\ Z}{200} \qquad (2)$$

$$\tan(\theta - \alpha) = \frac{\%\ I\ R}{\%\ I\ X} \qquad (3)$$

where

$O\ A$ = Voltage of bus near load,
$O\ B$ = Voltage of bus far from load,
$2\ \alpha$ = Phase angle between voltages $O\ A$ & $O\ B$,
θ = Phase angle of current in transmission line at load end,
$\%\ I\ R$ & $\%\ I\ X$ = Line constants including step-up and step-down transformers.

These equations are plotted in Fig. 4 by means of which it is possible to determine readily the phase angle θ of current in the interconnecting transmission line when the per cent impedance drop and the ratio of resistance to reactance is known.

Current Relations. The corresponding current relations can be easily derived from the vector diagram, Fig. 3, showing the current relations in terms of the power factor of the load being delivered and the power factor of the transmission line. In this it is assumed that the currents supplied by the two systems to the load are equal,

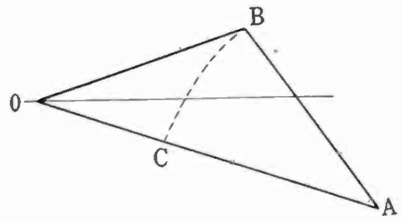

Fig. 3—Current Relations in Interconnected Systems

$O\,B$—Equals current in transmission line,
$B\,A$—Equals current at Station "A",
$O\,A$—Equals load current
Load power factor cos ϕ equals 95 per cent
Angle of lead in transmission line θ equals 20 deg.

under which condition the triangle of current $O\,B\,A$ is isosceles where $O\,A$ is the load current lagging an angle ϕ behind the voltage, $O\,B$ is the current delivered by the transmission line at the angle θ, and $B\,A$ is the current delivered by the local bus. A measure of the effectiveness of the transmission line and distant station in helping out the local station is determined by the ratio $O\,C\,/\,O\,B$, the point C being determined by making $C\,A$ and $B\,A$ equal to each other. This ratio, which may be called the transmission utility

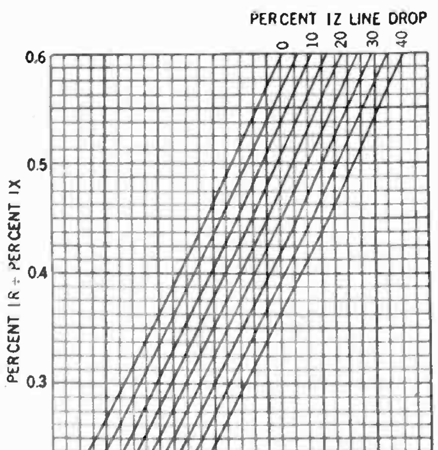

Fig. 4—Relation between Transmission Line Characteristics and Phase Angle for Zero-Line Drop

factor, can be expressed mathematically by the equation derived directly from Fig. 3.

$$T_u = O\,C/O\,B = 2\cos(\theta + \phi) - 1 \qquad (4)$$

This equation is plotted in Fig. 5, from which for various values of phase angles of currents in the transmission line and for various power factors of load, the transmission utility factor can be determined.

By means of Figs. 4 and 5 it is possible to determine the resulting transmission utility factor, when the transmission line constants are known, for any power factor of load. The curves show exactly how much is sacrificed in order to obtain constant potential on the two busses.

Rating of Transmission Line Less than Generating Stations. In the preceding analysis it was assumed

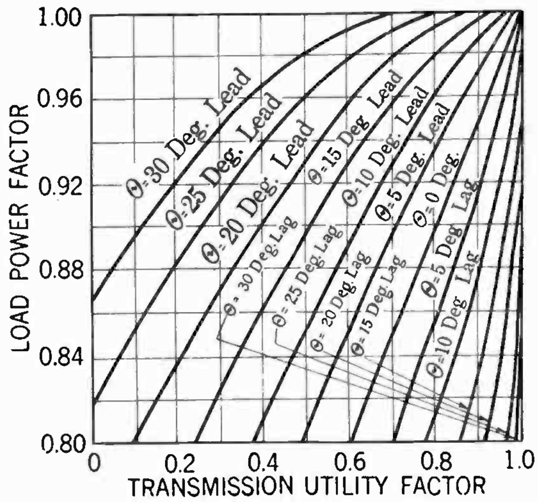

Fig. 5—Transmission Utility Factor of Transmission System and Distant Generator; f = 1.0

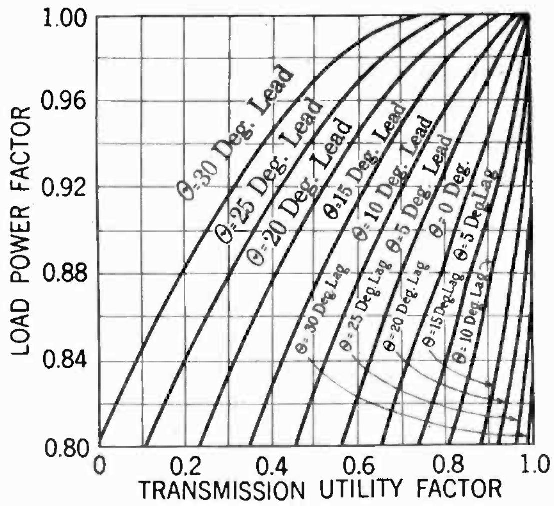

Fig. 6—Transmission Utility Factor of Transmission System and Distant Generator; f = 0.8

that the kilovolt-ampere rating of the transmission line was equal to the kilovolt-ampere rating of the generating stations, and for that reason the current in the transmission line and the current in the local generating station were made equal to each other. It may be, however, that the kilovolt-ampere rating of the transmission line is less than the rating of the stations, and for that reason, it becomes desirable to consider the case in which the division of load between the two stations is unequal. It is desirable, therefore, to have utility factor curves for various ratios of current in transmission line to current in generator nearest to the load. Let

$$\frac{\text{Current in Transmission Line}}{\text{Current in Generator nearest to Load}} = F$$

The curves, Figs. 5, 6 and 7, correspond to values of $F = 1$, $F = 0.8$ and $F = 0.5$, respectively.

It is of interest to note that in all of these cases, Figs. 5, 6 and 7, that a transmission utility of 100 per cent is obtainable only when the currents in the transmission line and in the generators of both stations are

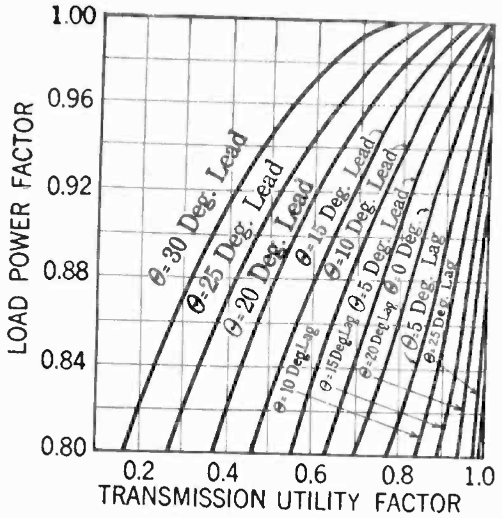

FIG. 7—TRANSMISSION UTILITY FACTOR OF TRANSMISSION SYSTEM AND DISTANT GENERATOR; $f = 0.5$

all in phase with the load current, no matter what the power factor of the load may be, and thus it is evident that the maintenance of constant potential on the two busses cannot be obtained under the conditions assumed without sacrificing the utility factor.

CASE II: ONE-WAY FLOW OF POWER—LINE DROP IN INTERCONNECTING LINE MAINTAINED CONSTANT

In case I, a two-way flow of power was assumed; consequently it was necessary to equate the line drop to zero. If the flow of power is in one direction only, it is sufficient that the line drop be maintained constant at all loads. A typical case is to assume 10 per cent line drop. For these assumptions, Fig. 8 has been determined giving the relations between the transmission line constants and phase angle of current in the transmission line. Fig. 8 is to be used in conjunction with transmission economy curves, Figs. 5, 6 and 7.

EXAMPLE FOR CASES I AND II

Transmission utility factors are determined in the following examples, in which constant voltage is maintained at two busses, by field control alone.[3]

3. It should not be inferred that all of the assumed operating conditions in the above examples represent good practise. They are merely cited to show the inherent difficulty of operating with field control alone. In the first example where a transmission factor of 18 per cent is obtained, the power factor in the generator is so poor, about 15 per cent lagging, that it is doubtful whether the generator could deliver its full kilovolt-ampere.

Two stations, A and B, 14 miles apart, interconnected by a 66-kv. transmission line, have a rating of 80,000 kv-a. At this load, the line characteristics including step-up and step-down transformers are:

		Per Cent
Reactance drop	=	32.5
Resistance drop	=	7.5
Impedance drop	=	33.5
r/x	=	0.23
Power factor of load	=	85

To determine the value of using ratio control in connection with the above conditions, it is first necessary to examine the operating conditions or limitations which exist if the two station busses are maintained at constant potential by means of generator field control only, that is, without employing ratio control or other voltage regulating devices. These conditions impose upon the system the necessity of maintaining the current in the transmission line at a definite phase angle, the values of which, as determined from Figs. 4 and 5, are:

For two-way flow of power (Fig. 4) θ = 22-deg. leading

For one-way flow of power (Fig. 8) θ = 4-deg. leading

The values of transmission utility factor for various conditions of operation as determined from Figs. 5, 6, and 7 are given in column 4 of the accompanying table. This value is a measure of the usefulness of the distant station under the conditions assumed. It means that

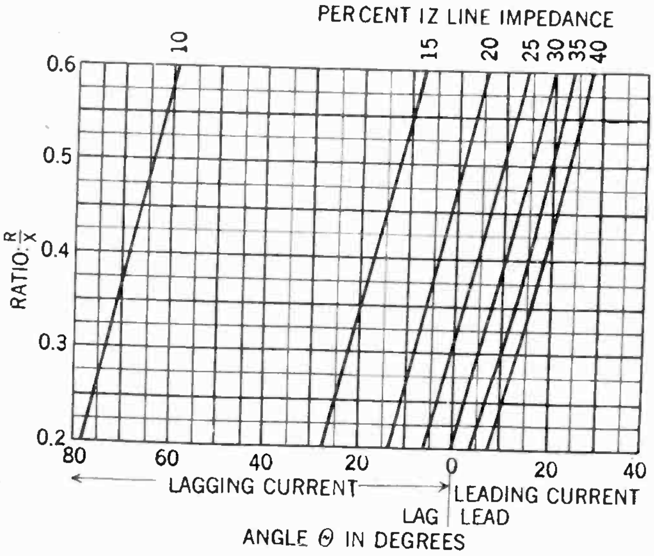

FIG. 8—RELATION BETWEEN TRANSMISSION LINE CHARACTERISTICS AND PHASE ANGLE FOR 10 PER CENT LINE DROP

although in each case the distant generator and transmission line are loaded to the rated kilovolt-ampere of the line, they are effective only to the extent indicated by the percentages given in column 4.

CASE III. COMPARISON OF SYNCHRONOUS CONDENSERS WITH TRANSFORMER RATIO CONTROL EQUIPMENT

Comparison of Ratings. When used for the purpose of enabling the system to hold bus volt-

CASE I: TWO-WAY FLOW OF POWER
Stations A and B Having Equal Ratings, Transmission Line Rating = 80,000 Kv-a.

1	2	3	4	
			Transmission Utility Factor	
	Rating station A and B	Ratio transmission line rating to station ratings	With field control only per cent	With ratio control only per cent
Fig. 5	80,000 kv-a.	1	18	100
Fig. 6	100,000 "	0.8	30	"
Fig. 7	160,000 "	0.5	42	"

CASE II: ONE-WAY FLOW OF POWER
Station B and Transmission Line Rating = 80,000 kv-a.

1	2	3	4	
			Transmission utility factor	
	Rating Station A	Ratio transmission line rating to station ratings	With field control only per cent	With ratio control only per cent
Fig. 5	80,000 kv-a.	1	62	100
Fig. 6	100,000 "	0.8	66	"
Fig. 7	160,000 "	0.5	72	"

ages at both ends of the line constant and independent of load changes, the synchronous condenser must compensate for the regulation of the line and interconnecting transformers. The condenser floating on the end of the line takes an additional wattless load the value of which, expressed in per cent of transmission line rating, is to be determined. The regulation due to the addition of the condenser load must be made equal and opposite to the regulation due to load. Hence

$$\left[\%\,(\text{Kv-a.})_c + \%\,(\text{Kv-a.})_c{}^1\right]\frac{\%\,I\,X}{100} = \%\,R \qquad (11)$$

where

$\%\,(\text{Kv-a.})_c$ = Rated leading kilovolt-ampere of condenser,

$\%\,(\text{Kv-a.})_c{}^1$ = Rated lagging kilovolt-ampere of condenser,

$\%\,I\,X$ = Per cent reactance drop of line without condenser,

$\%\,R$ = Per cent regulation of line without condenser,

from which the condenser rating can be determined when the regulation of the line, without condenser, is known.

The rating of load ratio control equipment for the same duty is:

$$\%\,(\text{Kv-a.})_{RC} = \frac{\%\,R}{2} \qquad (12)$$

Combining equations (**11**) and (**12**)

$$1/2\left[\%\,(\text{Kv-a.})_c + \%\,(\text{Kv-a.})_c{}^1\right]\frac{\%\,I\,X}{100} = \%\,(\text{Kv-a.})_{RC} \qquad (13)$$

which means that line reactance determines the relative size of condenser and ratio control apparatus for the same performance.

In equations (**12**) and (**13**) the fraction ½ is inserted assuming that the ratio control equipment has equal plus and minus ranges. This is generally, but not always, the case.

These equations determine the sum of the leading and lagging ratings of the condenser. They also show that as far as voltage control is concerned, it is immaterial how much of the sum is lagging and how much is leading.

Assuming that the first cost per kilovolt-ampere of ratio control equipment is appreciably less than the cost per kilovolt-ampere of synchronous condenser, it becomes evident from equation (**13**) that the first cost of ratio control equipment is inherently much less than the synchronous condenser.

Increased Output of System Due to Condenser. The costs of the *two* equipments are not directly comparable owing to the fact that the use of the condenser increases the output of the system. The amount can be determined from Fig. 9. As the maximum load is increased by the condenser current, the energy remaining constant, we can write:

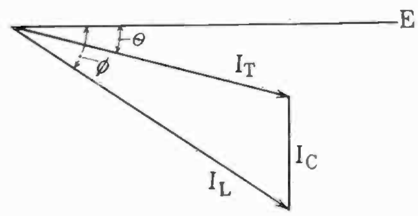

FIG. 9—CURRENT DIAGRAM SHOWING EFFECT OF SYNCHRONOUS CONDENSER ON TRANSMISSION LINE CURRENTS

$$(\text{Kv-a.})_L \cos\phi = (\text{Kv-a.})_T \cos\theta$$

or

$$(\text{Kv-a.})_L = (\text{Kv-a.})_T \frac{\cos\theta}{\cos\phi} \qquad (14)$$

where

$(\text{Kv-a.})_T$ = rating of generating plant,

$(\text{Kv-a.})_L$ = Kv-a. delivered to load,

which means that the ratio of the power factor of the load to the power factor of the line determines the increase in kilovolt-ampere of system on account of the condenser.

Perhaps the best way of obtaining an equable cost comparison between the use of a condenser and ratio control equipment is to determine the extra cost involved when ratio control is used to increase the system kilovolt-ampere by the ratio $\cos\theta/\cos\phi$. Ordinarily this merely involves providing the generators and interconnecting transformers with a correspondingly greater current carrying capacity. The increase in current in the overhead transmission line does not necessarily involve an increase in copper since the only practical effect of the increased current is greater line losses and increased regulation drop. An exception to this should be noted in the case of underground cables where the consideration of operating temperatures may make it undesirable to increase the maximum current. In this case the saving in cable equipment secured by employing the synchronous condensers may more than off-set its greater first cost.

Saving in Line Losses Obtained by Means of Synchronous Condenser. Consideration must also be given to the fact that the synchronous condenser, by improving the power factor of the line currents, decreases the copper losses in the line. The ratio of line copper losses with and without using the condenser is given by the expression:

$$\text{Loss ratio} = \left(\frac{\cos\phi}{\cos\theta}\right)^2 \qquad (15)$$

Improving, by condenser, the power factor from 80 per cent to 95 per cent, for example, reduces the line loss 25 per cent. Where poor power factor of load is combined with inherently large line losses, the saving in losses at full load due to the use of condensers is considerable.

The actual saving in loss, however, is less than may

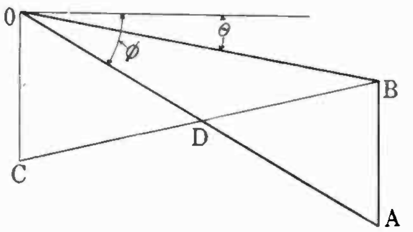

FIG. 10—CURRENT DIAGRAM FOR FRACTIONAL LOADS SHOWING EFFECT OF SYNCHRONOUS CONDENSER WITH MAXIMUM LAGGING CURRENT EQUAL TO MAXIMUM LEADING CURRENT

be inferred from the above, on account of the fact that under usual operating conditions the load factor is considerably less than unity. At fractional loads, the saving in losses resulting from the condenser is very much reduced, and at light loads, when condensers is operating lagging, the line losses are actually increased by the condenser. It is reasonable to expect, therefore, that under normal conditions of load, the actual net saving in line losses is much less than the value obtained for full load conditions.

From this it appears that the saving in line losses is very much affected by (a) the load factor and (b) the ratio of leading and lagging rating of the synchronous condenser.

Losses in Condenser vs. Losses in Ratio Control Apparatus. Furthermore, the net line losses saved by condenser are off-set partially by the fact that the transformer ratio control apparatus is inherently considerably more efficient than synchronous condensers, for several reasons:

1. On account of the smaller kilovolt-ampere rating of transformers,

2. On account of the inherently higher efficiency of transformers,

3. On account of the fact that in transformer ratio control, both the core and copper losses may be variable. The core loss varies from maximum to minimum when voltage ratio is shifted from maximum value to unity and the copper losses vary from maximum to minimum with changes in load.

To form a correct comparison between the two equipments, the actual values of the various losses just cited must be carefully estimated and capitalized.

EXAMPLE ILLUSTRATING CASE III

Assuming the following conditions:

	Per Cent
Line reactance drop	29
Line resistance drop	7
Power factor of load	86

it is desired to compare the use of ratio control equipment with a synchronous condenser when used to maintain voltage at both ends of line constant. Under these conditions the line regulation without the condenser is 22.7 per cent. By equation (**12**) the rating of ratio control equipment necessary to maintain voltage constant is 11.3 per cent of the kilovolt-ampere of the load.

By equation (**13**) the rating of the condenser is per cent $(\text{kv-a.})_c$ + per cent $(\text{kv-a.})_c^1$ = 70 per cent

The synchronous condenser performance depends upon the ratio of the leading and lagging rating of the condenser. Assuming equal leading and lagging ratings, in other words, per cent $(\text{kv-a.})_c$ = per cent $(\text{kv-a.})_c^1$ = 35 per cent, current relations are obtained as shown in Fig. 10. At full load the addition of the condenser brings the line power factor up to 99 per cent. The ratio of line power factor to load power factor is 1.14, which means that the system rating has been increased by 14 per cent, equation (**14**). The full load line losses by equation (**15**) are 77 per cent of what they would be without the condenser. The triangle $O\,B\,D$ in Fig. 10 gives the current relations for full load; $O\,C$ is the condenser current at no load; and the line $C\,D\,B$ is the locus of the line current as the load increases from no-load to full load. At the intersect D corresponding to half load for Fig. 10, the condenser is not contributing. For less than half load the condenser is increasing the line losses, and for loads greater than half load the line losses are decreased by the condenser.

The current diagram, Fig. 11, corresponds to the assumption that the leading rating of the condenser is 46.5 per cent and the lagging rating is 23.5 per cent. The chief difference between Figs. 10 and 11 is the position of the intersect D, which now occurs at 33 per cent load. It is evident that operation, in accordance with the assumption upon which Fig. 11 is based, means a greater saving in line losses for a given load factor than operation in accordance with conditions assumed for Fig. 10.

CASE IV. TRANSMISSION LINE LOOP

Under cases I and II it was shown that by the help of one voltage control equipment constant voltage can be maintained at two points and at the same time any desired current relation obtained. The principle can be extended to any number of stations operating on a line so that with N stations and $N - 1$ voltage control equipments it is possible to maintain the bus voltage constant at N stations and at the same time secure any desired division of current in each portion of the line.

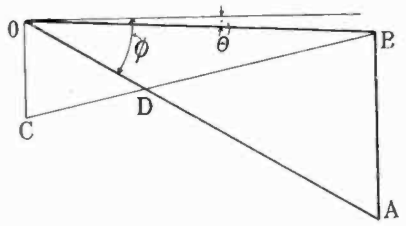

FIG. 11—CURRENT DIAGRAM FOR FRACTIONAL LOAD, SHOWING THE EFFECT OF SYNCHRONOUS CONDENSER WITH MAXIMUM LAGGING CURRENT 50 PER CENT OF MAXIMUM LEADING CURRENT

At each station voltage control may be inserted between high and low voltage of the power transformers as shown in Fig. 12, or the variable voltage may be inserted in series with the line as shown in Fig. 13. In the former case the over-all regulation of the line is unaffected, whereas in the latter case the variable voltage being inserted in the line itself, not only the station bus voltage but also the line voltage, is affected.

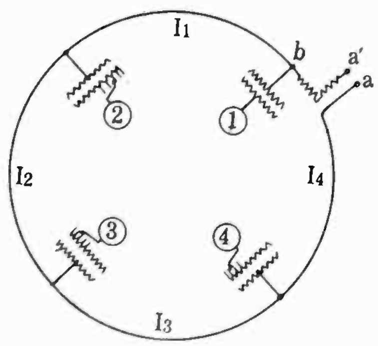

FIG. 12—TRANSMISSION LINE LOOP PROVIDED WITH IN-PHASE AND QUADRATURE VOLTAGE CONTROL

When the two ends of the lines a and b, in either Fig. 12 or 13, are connected together forming a loop, it is desirable to know whether complete current flexibility is still obtainable. It is evident for example, that if the currents in the four portions of the line, in Figs. 12 and 13, are to be independently variable, a variable voltage exists between a and b which is the resultant of the impedance drops in the four lines. This voltage (e) varies in value and in phase from time to time depending upon how much the currents are changing in the line. We may write for the voltage between a and b for Fig. 12

$$e = I_1 Z_1 + I_2 Z_2 + I_3 Z_3 + I_4 Z_4$$

where

$I_1 I_2 I_3 I_4$ are the currents desired in the lines;

$Z_1 Z_2 Z_3 Z_4$ are the corresponding line impedances.

For Fig. 13 the expression becomes:

$$e = I_1 Z_1 + I_2 Z_2 + I_3 Z_3 + I_4 Z_4 - e_2 - e_3 - e_4$$

where

e_2, e_3, e_4 are the control voltages inserted in the line at stations 2, 3 and 4.

If the loop is formed by connecting a and b without inserting any control equipment, the voltage (e), as given in the above equations, is short-circuited and a circulating current flows throughout the loop, the value of which is given by the expression,

$$I_c = e/(Z_1 + Z_2 + Z_3 + Z_4)$$

The line currents have now become

$$I_1 + I_c$$
$$I_2 + I_c$$
$$I_3 + I_c$$
$$I_4 + I_c$$

It is evident that the desired currents, I_1, I_2, I_3, I_4, can

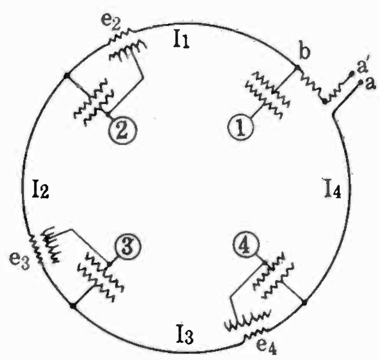

FIG. 13—TRANSMISSION LINE LOOP PROVIDED WITH IN-PHASE AND QUADRATURE VOLTAGE CONTROL

be obtained only in the remote coincidence that these currents happen to be of such values as to make the resultant voltage (e) zero. The alternative is to introduce into the line a voltage which is always equal and opposite to (e). Therefore, if the ends a and b are to be connected without interfering with current flexibility, it is necessary to bridge the points a and b with a voltage which is equal to, and in phase with, the vector sum of the impedance drops in the lines.

The insertion of such a low impedance voltage bridge between points a and b in which the voltage and also the phase angle are independently controllable can be accomplished by two ratio control equipments, one providing the proper in-phase voltage and the other providing the proper quadrature voltage. (See note following.)

In general, a transmission line loop in which a maximum current flexibility is desired together with N points maintained at constant potential, requires N voltage ratio controls and one quadrature control.

Although two independent controls, consisting of an in-phase and a quadrature control, are necessary to obtain complete flexibility, nevertheless, under particular conditions of load variation, one ratio control equipment is sufficient for loop control.[4]

For example, when the currents I_1, I_2, I_3, I_4 vary during the load cycle in such a manner that the resultant voltage (e) changes in value but not in phase, it is then only necessary to determine the phase angle of (e) with reference to the line voltage, and to design loop control equipment having this angle.

Loop control may be needed to prevent excessive current flowing in portions of circuit as, for example, when underground cables are used having a limited current rating, or it may be desired in order to be able at all loads to obtain a minimum of energy loss in the loop. In the latter case the exact setting of the control equipment can be calculated readily.

Current Distribution with Reference to Obtaining Minimum Energy Losses in Loop. At the end of this paper, equations are developed which give the condition for current distribution so as to obtain minimum energy losses in the loop. These equations show that the criterion for minimum losses is the condition that the vector sum of the resistance voltage drops around the loop should be zero. This criterion can always be met by means of two control equipments if they are so adjusted as to allow a circulating current to flow through the loop in accordance with

$$R\,I_c + \Sigma r\,I = 0$$

where

I_c is the circulating current,

R is the total resistance of the loop,

$\Sigma r\,I$ is the vector sum of the resistance drops (not including the drop due to circulating current).

To obtain this current distribution, the control equipments must introduce the following voltages into the line: An in-phase voltage equal to

$$e = j_1\,x_1 + j_2\,x_2 + j_3\,x_3 + \text{etc.}$$

and a quadrature voltage equal to

$$j\,e = i_1\,x_1 + i_2\,x_2 + i_3\,x_3 + \text{etc.}$$

An important particular case is when the ratio of resistance to reactance in each portion of the line is equal; that is, when

$$\frac{x_1}{r_1} = \frac{x_2}{r_2} = \frac{x_3}{r_3} = \frac{X}{R}$$

where R and X are the total resistance and reactance of the loop. Then

$$x_1 = \frac{r_1}{R}X \quad x_2 = \frac{r_2}{R}X \quad x_3 = \frac{r_3}{R}X$$

When these values are substituted in the equations for e and $j\,e$, they reduce to the following simple form:

$$j\,e = \sum r\,i\frac{X}{R}$$

$$e = \sum j\,r\frac{X}{R}$$

But by the conditions of the problem $\Sigma i\,r = 0$ and $\Sigma j\,r = 0$. It therefore follows that both e and $j\,e$ are zero. The important conclusion follows that when the ratios of resistance to reactance in each portion of the loop are all equal to each other, the currents distribute in the loop so as to obtain minimum copper loss, when the loop is closed without voltage inserted. Loop control equipment is therefore necessary only by virtue of the fact that the various portions of line have different ratios of resistance to reactance.

Acknowledgment is hereby made to Raymond Bailey, P. J. Walton, W. W. Lewis, H. O. Woods and M. B. Mallett for their assistance in the preparation of this paper.

An appendix with equations to find the current distribution in a loop with reference to obtaining minimum energy losses in a loop is included in the complete paper.

4. Loop control can also be obtained by means of two polyphase inductive regulators, the series windings being mounted in the line and connected in series with each other. Each regulator inserts in the line a constant voltage with phase angle variable from zero to 360 deg. By adjusting their phase angles, the combined voltage introduced into the line can be made any desired value and any angle.

Bibliography

Voltage Control Obtained by Varying Trans. Ratio, L. F. Blume, A. I. E. E., JOURNAL, July, 1925, p. 752.

Changing Trans. Ratio Without Interrupting Load, M. H. Bates, A. I. E. E. JOURNAL, November, 1925, p. 1238.

Trans. Tap Changing Under Load, H. C. Albrecht, A. I. E. E. JOURNAL, December, 1925, p. 581.

Electrical World, March 6-27, 1926, "Tap Changing Transformers: With Nine Steps—With Eighteen Steps," A. Palme.

G. E. Review, May, 1926, "Arrangement for Load Ratio Control," H. R. Wilson.

Electrical Journal, May, 1926, "Trans. Volt Ratio Control under Load," L. H. Hill.

G. E. Review, September, 1926, p. 634-638, "Two 60,000-Kv-a. Load Ratio Control Transformer Banks for Philadelphia Electric Company," A. Palme and H. O. Stephens.

The Induction Voltage Regulator, p. 301-317, "The Function of the Induction Regulator in the Interconnection of Power Systems," E. F. Gehrkens.

Elektrotechnische Zeitschrift, October 21, 1926, "Economy of Voltage Regulations in Three-Phase Networks," Bernhard Jansen.

Elektrotechnische Zeitschrift, February 3, 1927, "Equi-potential Operation of Three-phase Networks," Bernhard Jansen.

Abridgment of

A Theory of Imperfect Solid Dielectrics

BY MICHEL G. MALTI[1]

Associate, A. I. E. E.

Synopsis.—This paper covers Chapters VII, VIII and IX of a thesis presented by the author to the Faculty of the Graduate School of Cornell University, for the degree of Doctor of Philosophy.

In this thesis a summary is made of the experimental facts regarding the anomalous behavior of solid insulating materials under varying conditions of potential, time, temperature, frequency, humidity, ionizing radiations and various other factors.

A bibliography containing about 400 articles dealing with experimental and theoretical research is appended to the thesis. These articles are chronologically arranged and numbered.

Five tables are given, including references to experimental research done on (a) dielectric resistivity, (b) dielectric charge and discharge, (c) dielectric constant, (d) dielectric strength, (e) dielectric energy loss.

Hypotheses are here established which account, in a general way, for the observed behavior of solid dielectrics. Definitions of the resistivity, permittivity, electric charge and electric strength of solid dielectrics under both continuous and alternating potentials are submitted. Terms are introduced and defined: e. g., the "(i — t)-characteristic," the "electrization curve," and the "hystero-viscosity loop."

The various energy losses occurring in dielectrics are traced to their sources and subdivided into hysteresis, viscosity and resistance losses. Methods are devised for separating the total dissipated energy into its three component parts.

Finally, the classical theory is shown to apply to imperfect solid dielectrics if the submitted definitions and terms be adopted.

* * * * *

Part II. Definitions of Terms

A. The Resistivity ρ of Solid Dielectrics

1. *Resistivity at Continuous Potential.*

The resistance R of a solid dielectric with a continuous applied potential will be defined as:

$$R = \lim_{t \to t_r} (E - 2\,E_p)/I_r \qquad (1)$$

The notations used in equation (1) may be visualized by referring to Fig. 4.

From equation (1) the resistivity ρ will be:

$$\rho = R\,a/d = [(E - 2\,E_p)/I_r]\,(a/d) \qquad (2)$$

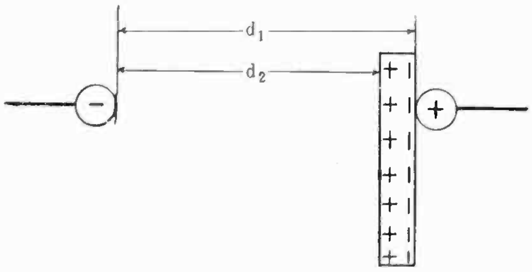

Fig. 2—Decrease in the Sparking Distance of a Gas due to Placing a Solid Dielectric Near the Anode

For continuous potentials, and within the same potential range, ρ will be constant. However, ρ will assume lower values as higher ranges of potential are reached until at the breakdown potential ρ becomes practically zero. The resistivity defined by equation (2) is easily measured because all the quantities on the right hand side are determinable. E_p is the only factor which seems difficult to measure. Its value, however, may be experimentally determined as was done in (53-15) and (2-25) by first impressing E for a time t_r, then suddenly decreasing E to such a value that i_r becomes zero. This new value of E at which $i_r = 0$ is the value of $2\,E_p$, while (53-15) shows that if this is done, R, (at least in the case of quartz and iceland spar), is not only independent of E, within certain limits, but is also independent of the time t.

2. *Resistivity at Alternating Potentials.*

The value of ρ can thus be experimentally determined when continuous potentials are used. With alternating potentials, the conduction current cannot be experimentally separated from the charging current. The method generally adopted of measuring the power dissipated in a condenser and taking ρ of such a value that $W = I^2 R$, is physically erroneous because of the fact that the energy dissipated is largely a hysteresis loss, and the $I^2 R$ loss forms but a very small percentage of the total dissipated energy (see 2/82, 94-12 and 17-15).

Two questions arise in regard to the resistivity when alternating potentials are used:

a. What conception must be formed of ρ with alternating potentials?

b. If ρ is a function of the potential range, what value of ρ must be adopted when alternating potentials assume instantaneous values which fall within more than one potential range?

The answer to the first question is that the concept of ρ with alternating potentials should not differ from that of ρ with continuous potentials.

The answer to the second question would lead to a definition of an effective resistance which, although having no physical basis when the potential gradient exceeds the initial range, leads to an approximate determination of the true $I^2 R$ loss when alternating potentials are used. Thus, let $t_1, t_2, \ldots\ t_n$ be the times at which the sinusoidal voltage wave (Fig. 3)

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assumes instantaneous values $e_1, e_2 \ldots e_n$ such that $e_1 = E_A, e_2 = E_B, \ldots e_n = E_N$, where $E_A, E_B \ldots E_N$ are the upper potential limits of the potential ranges, $A, B \ldots N$.

Then

$$\left.\begin{aligned} W_{r1} &= \int_0^{t_1} (i_{rA})^2 R_A\, dt = R_A \int_0^{t_1} (i_{rA})^2\, dt \\ W_{r2} &= \int_{t_1}^{t_2} (i_{rB})^2 R_B\, dt = R_B \int_{t_1}^{t_2} (i_{rB})^2\, dt \\ &\cdots\cdots \\ W_{rn} &= \int_{t(n-1)}^{t_n} (i_{rN})^2 R_N\, dt = R_N \int_{t(n-1)}^{t_n} (i_{rN})^2\, dt \end{aligned}\right\} \quad (3)$$

where $i_{rA}, i_{rB}, \ldots i_{rN}$ are the conduction currents, $R_A, R_B, \ldots R_N$ are the resistances and $W_1, W_2 \ldots W_n$ are the energy losses that would be obtained at continuous potentials lying within the ranges $A, B \ldots N$.

The value of the first integrand in equation (3) will then be

$$W_{r1} = R_A \int_0^{t_1} [(I_{rA}\sqrt{2}) \sin \omega t]^2\, dt$$

$$= (I_{rA}^2 R_A) \left[t_1 - \frac{\sin 2\,\omega t_1}{2\,\omega} \right] \quad (4a)$$

The other integrands in equation (3) cannot be so easily evaluated because, according to the eighth hypothesis, we cannot assert that the conduction currents $I_{rB} \ldots I_{rN}$ are sinusoidal. However, if we should follow the procedure adopted in obtaining equation (4a), the error will be only in the deviation of the current from the sinusoidal value. This error, for potential gradients lying well below the rupturing gradient G_s, cannot be very large. We shall therefore evaluate the remaining integrands as was done in the case of the first and obtain:

$$W_{r2} = (I_{rB}^2 R_B) \left[(t_2 - t_1) - \frac{\sin 2\,\omega t_2 - \sin 2\,\omega t_1}{2\,\omega} \right] \quad (4b)$$

$$\cdots\cdots$$

$$W_{rN} = (I_{rN}^2 R_N) \left[(t_n - t_{n1}) - \frac{\sin 2\,\omega t_n - \sin 2\,\omega t_{n-1}}{2\,\omega} \right] \quad (4n)$$

Therefore the total energy dissipated per ¼ of a cycle is:

$$W_r = (W_{r1} + W_{r2} + \ldots + W_{rN}) \quad (5)$$

But with actual conducting materials the energy loss due to the passage of a current of effective value I_{rN} for a period of time $T/4$ is:

$$W_{rN} = I_{rN}^2 R_N T/4$$

from which

$$R_N = 4\, W_{rN}/I_{rN}^2 T \quad (6)$$

The equivalent resistance of a dielectric at sinusoidal potentials, having instantaneous values which extend over more than one potential range, may be analogously defined as

$$R_{eq} = 4\,(W_{r1} + W_{r2} + \ldots W)_{rN}/I_{rN}^2 T \quad (7)$$

where $W_{r1}, W_{r2} \ldots W_{rN}$ are defined by equations (4)

At voltages whose amplitudes do not exceed the initial potential range, equation (4a) for ¼ of a cycle becomes:

$$W_r = I_{rA}^2 R_A T/4 \quad (8)$$

Therefore, the resistance of a slab of dielectric at such

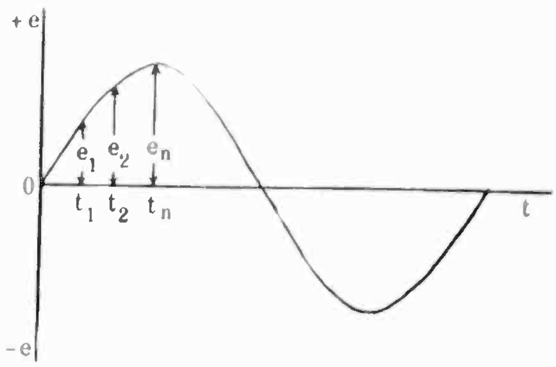

FIG. 3—A SINE WAVE OF VOLTAGE

alternating potentials is equal to that obtained by using a continuous potential of a magnitude equal to the effective value of the alternating potential.

It must be remembered that I_{rA} in equation (8) is

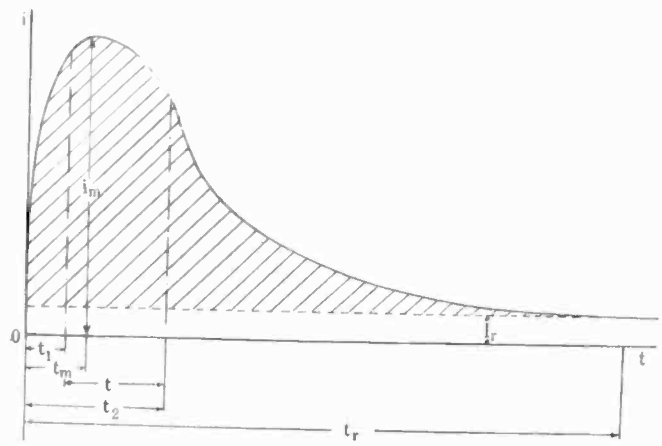

FIG. 4—THE $(i - t)$-CHARACTERISTIC OF A SOLID DIELECTRIC

not the effective value of the alternating current, flowing through the condenser, as measured with an a-c. ammeter. It actually corresponds to I_r in equation (1); *i. e.*, it is the true conduction current read at a time t_r on a d-c. instrument, when a continuous potential of a magnitude equal to the effective value of the alternating potential is applied to the condenser.

B. ELECTRIC CHARGE AND DISCHARGE OF SOLID DIELECTRICS

1. *The Charge with Continuous Potentials.*

a. Definition: If, for a definite temperature, humidity, and continuous potential, current readings be taken, at various intervals of time, for a circuit with R, L, and C, then, upon plotting those readings, Fig. 4 will be obtained.

The charge acquired by the dielectric in the interval of time $t = (t_2 - t_1)$ will be defined thus:

$$Q = \int_{t_1}^{t_2} (i - I_r)\, d\, t = \int_{t_1}^{t_2} i_c\, d\, t \qquad (9)$$

In equation (9), i is the current measured at any instant and I_r is the leaky current represented by

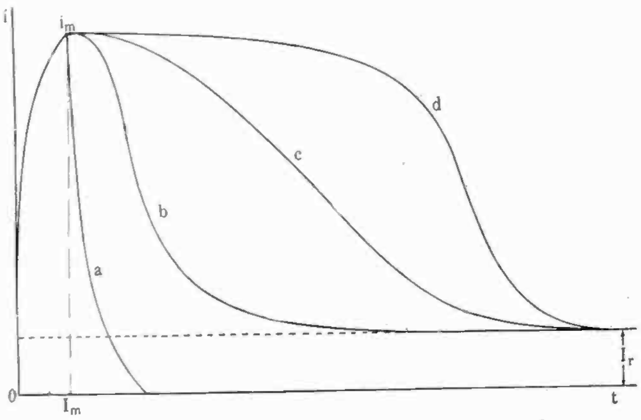

FIG. 5—VARIOUS SHAPES OF THE $(i - t)$-CHARACTERISTICS OF SOLID DIELECTRICS

the constant value which it assumes after a time t_r; see equation (1).

b. Remarks on Fig. 4.

1. The value of the charge Q, expressed by equation (9), can be graphically represented by that part of the shaded area in Fig. 4, included between t_1 and t_2. It will be noted that Q is a function not only of the magnitude, $t = t_2 - t_1$, of the time interval, but also of the actual values of the limits t_1 and t_2. For the extreme case where $t_1 = t_r$ and $t_2 > t_r$, the charge is zero because $i - I_r = 0$.

2. The time t_m, corresponding to the maximum value i_m, is solely a function of the constants R, L and C of the circuit. It can be reduced to a minimum by making $L \to O$.

3. The actual value i_m is a function of the dielectric material, the applied voltage gradient, temperature and various other factors.

4. The character of that section of the curve which extends from t_m to t_r is an indication of the relative number of the three types of the electrons present in the dielectric as well as the degree of viscosity of the electrons belonging to the second order. Indeed, the curve is a function of the rate of growth of the polarization e. m. f. which forms on the boundary surface between the plates and the dielectric. This is best illustrated by Fig. 5, where curves are drawn for various materials possessing the same dielectric resistivity but having different $(i - t)$ - characteristics.

Curve a represents the $(i - t)$ - characteristic of an ideal condenser. The ascending and descending portions of the curve are identical. The descending part of the curve is a reproduction of the inverted ascending portion. Moreover, owing to the perfect elasticity of the ether, i_m is just a point on the curve. Again the final current becomes zero because a perfect condenser is devoid of any conductivity.

Curve b stands for a condenser whose dielectric is rich in highly elastic electrons; the portion of the curve beyond t_m is very steep, showing that each of the viscous electrons possesses, to a more or less extent, the same degree of viscosity. That the value of i_m extends for a certain length along the curve, is an indication of the existence of viscous electrons, because it shows that the polarization took some time before approaching its steady final value.

Curve c is drawn for a condenser whose electrons have varying degrees of viscosity as indicated by the gentle slope of the curve and the time it takes for the polarization to be complete.

Curve d shows that although the electrons are very highly viscous, as indicated by the time required for the first point of inflection to occur, there exists very little difference in their degrees of viscosity. The very steep descent of the curve, as soon as the polarization attains its final value, is an indication of this latter fact.

5. While, in general, a dielectric which possesses the characteristic *Curve b* (Fig. 4) within a certain potential or temperature range, may be expected to exhibit a similar characteristic at other ranges, it must not be inferred that this always holds true. Indeed the behavior of a dielectric is a very complicated function of its internal structure. Therefore, it is very

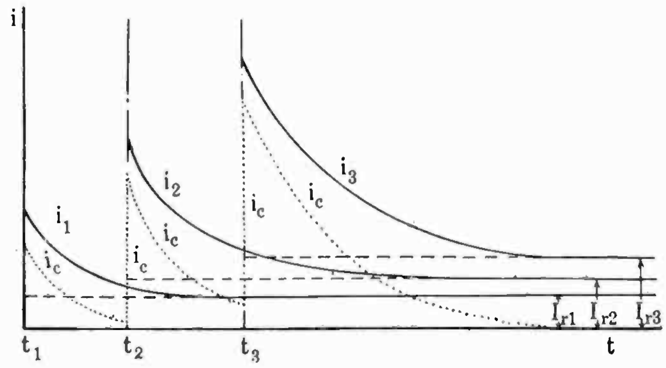

FIG. 6—THE RESULTANT CHARGING CURRENT DUE TO SUCCESSIVELY INCREASING POTENTIALS IMPRESSED UPON A DIELECTRIC

likely that the same dielectric will exhibit the various characteristics represented by *Curves b, c* and *d*, at different potential ranges. This will be in strict conformity with the hypotheses laid down in Part I.

2. *The Charge with Alternating Potentials.*

a. Some Laws and Corollaries: The $(i - t)$-characteristic represented by Fig. 4 is true for steady continuous potentials. With alternating potentials the shape of the current—time curve is further complicated by the fact that e is a function of time.

Before formulating a definition of charge with alternating potentials we shall cite the laws of charge and discharge established in 2/89, taking the liberty to introduce such changes in them as have been necessitated by more recent researches.

Law 1. Within the initial potential range and for the same conditions of temperature, humidity, etc., the value of $i_c = (i - I_r)$ for a dielectric at one and the same instant of time (t), after impressing the potential, is proportional to the applied potential E. Thus, if i_c and i_c' are the charging currents measured at an instant t after impressing voltages E and E', respectively, and if E and E' are both less than the upper limit E_A of the initial potential range A, then

$$E/E' = i_c/i_c' \tag{10}$$

Law 2. The charging current i_c, due to successively increasing potentials impressed at successive instants on a condenser, is equal to the sum of the charging currents that would be produced by each potential acting alone, provided none of these potentials exceeds the upper limit E_A of the initial potential range. Thus,

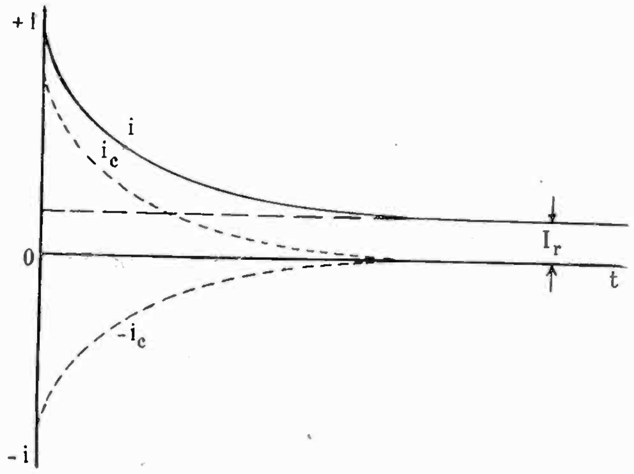

Fig. 7—The Charge and Discharge Currents of a Solid Dielectric

let $E_1, E_2, E_3 \ldots E_n$ be successively impressed on a condenser at times $t_1 < t_2 < t_3 \ldots < t_n$ and let $E_1 < E_2 < E_3 < \ldots < E_n < E_A$, then

$$i_{c1} + i_{c2} + i_{c3} \ldots + i_{cn} = i_c \tag{11}$$

In order to visualize this law, imagine a circuit of such a small inductance that the time t_m, Fig. 4, may be neglected. The voltages $E_1, E_2 \ldots E_n$ applied at times $t_1, t_2 \ldots t_n$ will give rise to the currents $i_1, i_2 \ldots i_n$; Fig. 6. Then the charging currents $i_{c1}, i_{c2} \ldots i_{cn}$ will be:

$$\left.\begin{aligned} i_{c1} &= i_1 - I_{r1} \\ i_{c2} &= i_2 - I_{r2} \\ &\ldots\ldots \\ i_{cn} &= i_n - I_{rn} \end{aligned}\right\} \tag{12}$$

and the instantaneous value of the total charging current $i_c = i_{c1} + i_{c2} + \ldots + i_{cn}$ will be represented by the dotted curve.

Corollary 1. As is pointed out by Curie (2/89), one consequence of Law 2 is that the charging current curve is identical with that for the discharge current curve, but of opposite sign. The discharging of a condenser at short circuit is indeed equivalent to introducing into the circuit a voltage $(-E)$, equal in magnitude, but opposite in direction, to that of the impressed voltage. If acting alone, this newly introduced voltage would cause a charging current identical in shape with, but opposite in sign to, the original charging current as is shown in Fig. 7.

Unfortunately this law does not apply to potentials higher than the upper limit of the initial potential range. (See references in hypothesis 7, Part I). This accounts for the limitation introduced in formulating the law and for the statement made in the eighth hypothesis.

Corollary 2. Up to a certain time t, the total charge acquired by a condenser, due to successively increasing potentials, is equal to the sum of the charges that would be acquired if each of the potentials were acting alone. Thus, if $i_{c1}, i_{c2} \ldots i_{cn}$ be the charging currents due to potentials $E_1 < E_2 < \ldots < E_n \ldots < E_A$, impressed at times $t_1 < t_2 < \ldots < t_n$, then the total charge Q acquired by the condenser from t_1 to $t > t_n$ is $Q = Q_1 + Q_2 \ldots + Q_n$ or

$$Q = \int_{t_1}^{t} i_{c1}\,d\,t + \int_{t_2}^{t} i_{c2}\,d\,t + \ldots + \int_{t_n}^{t} i_{cn}\,d\,t \tag{13}$$

Law 3. The value of the charging current i_c due to a continuous potential E applied to a condenser for more than an infinitesimally short interval, (*i. e.*, an interval sufficiently long to cause a displacement of the elastic electrons but not of the viscous electrons), is proportional to the interval of time through which the potential acts.

This is a very specious law; it will always remain as a hypothesis because it does not lend itself to experimental verification. Its plausibility will be evident, however, if we admit the hypotheses postulated in Part I. Indeed, if viscous electrons require some time to attain their final displacement, one would naturally expect the time element to enter as a necessary factor in determining the value of i_c.

b. The Equations for the Charging Current and Charge Acquired with Alternating Potentials. Let the potentials $E_1, < E_2, < \ldots < E_n$ be comprised between the limits 0 and E_m, and let $t_1 < t_2 < t_3 \ldots > t = T/4$ be the times at which these potentials are applied. Let E_m be the amplitude and T the period of the sinusoidal applied potential whose equation is

$$e = E_n \sin \omega t \tag{14}$$

then

$$\left.\begin{aligned} E_1 &= E_m \sin \omega t_1 \\ &\ldots\ldots \\ E_n &= E_m \sin \omega t_n \end{aligned}\right\} \tag{15}$$

According to the first law expressed by equation (10), the value of the charging currents i_u and i_v, measured at the same instant, t, after impressing E_u and E_v respectively, is

$$i_{cu}/i_{cv} = E_u/E_v = [E_m \sin \omega t_u / E_m \sin \omega t_v]$$
$$= \sin \omega t_u / \sin \omega t_v \qquad (\mathbf{16})$$

and for the particular case where $t_v = T/4$ equation (**16**) becomes

$$i_{cu}/i_{cm} = E_u/E_m = \sin \omega t_u/1$$

whence

$$i_{cu} = (\sin \omega t_u)\, i_{cm} \qquad (\mathbf{17})$$

In what follows, two notations for time, t and τ, will be adopted in order to differentiate between time measured along the abscissa of the voltage curve, (Fig. 8A), and that measured along the abscissa of the $(i - t)$ characteristic, (Fig. 8B). Therefore, t will be used for voltage variation and τ for charging-current variation with time.

Let

$$i_{cm} = f\left(\tau - \frac{T}{4}\right) \qquad (\mathbf{18})$$

be the function expressing the value of the charging current due to a continuous potential (of magnitude (E_m) equal to the maximum value of the alternating

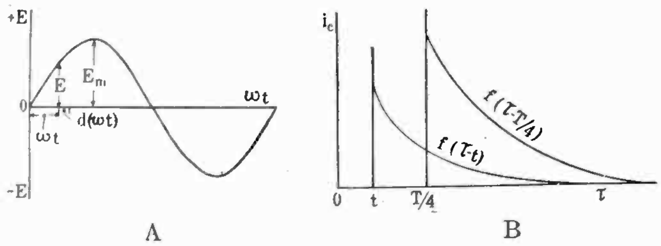

FIG. 8

A—A SINE WAVE OF POTENETIAL

B—THE CHARGING CURRENTS DUE TO TWO INSTANTANEOUS VALUES OF AN ALTERNATING POTENTIAL

potential) which is impressed on the condenser at time $t = \frac{T}{4}$. Then the function expressing the value of the charging current for any other continuous potential of magnitude $E = E_m \sin \omega t$ impressed on the condenser at a time t and acting through an angle $d\,(\omega t)$ will be, by equation (**17**) and law 3,

$$I_c' = f(\tau - t)\,(\sin \omega t)\, d\,(\omega t) \qquad (\mathbf{19})$$

and the total current at any time $\tau \gtreqless t$ due to all the instantaneous voltages from 0 to τ each of which acts for an interval $d\,(\omega t)$, will be:

$$i_c = \int_0^{\tau} f(\tau - t)\,(\sin \omega t)\, d\,(\omega t) \qquad (\mathbf{20})$$

and the charge Q acquired during ¼ of a cycle is

$$Q = \int_0^{T/4} i_c\, d\tau = \int_0^{T/4} \left[\int_0^{T/4} f(\tau - t)\,(\sin \omega t)\, d\,(\omega t) \right] d\tau \qquad (\mathbf{21})$$

The same reasoning can be extended to potentials with instantaneous values exceeding the initial potential range. Referring to Fig. 4, let $t_1, t_2 \ldots t_n$ be the times at which the sinusoidal voltage assumes instantaneous values $e_1, e_2 \ldots e_n$, so that $e_1 = E_A$, $e_2 = E_B, \ldots e_n = E_N$, where $E_A, E_B, \ldots E_n$ are the upper potential limits of the potential ranges $A, B, \ldots N$, respectively. Let $f_A\,(\tau - t_1)$, $f_B\,(\tau - t_2) \ldots f_N\,(\tau - t_n)$ be the functions expressing the variations of $i_{c1}, i_{c2}, \ldots i_{cn}$ with τ at continuous voltages $E_A, E_B, \ldots E_N$. Then, by analogy with equation (**21**), the value of i_c at any time, τ, according to the corrections indicated, equation (**20a**) will become:

$$\left.\begin{aligned}
i_{cA} &= \int_0^{\tau} f_A(\tau - t)\,(\sin \omega t)\, d\,(\omega t) && 0 \leqq \tau \leqq t_1 \\
i_{cB} &= \int_0^{t_1} f_A(\tau - t)\,(\sin \omega t)\, d\,(\omega t) + \int_{t_1}^{\tau} f_B(\tau - t)\,(\sin \omega t)\, d\,(\omega t) && t_1 \leqq \tau \leqq t_2 \\
&\cdots\cdots\cdots \\
i_{cN} &= \int_0^{t_1} f_A(\tau - t)\,(\sin \omega t)\, d\,(\omega t) + \int_{t_1}^{t_2} f_B(\tau - t)\,(\sin \omega t)\, d\,(\omega t) + \cdots \\
&\quad + \int_{t(N-1)}^{t} f_N(\tau - t)\,(\sin \omega t)\, d\,(\omega t) && t_{N-1} \leqq \tau \leqq t_n
\end{aligned}\right\} \qquad (\mathbf{20a})$$

The charge acquired by the condenser will be:

$$Q = \int_0^{T/4} i_{cN}\, d\tau \qquad (\mathbf{21a})$$

where i_{cN} is expressed by equation (**20a**).

c. Discussion of Equations (**21**) and (**21a**). In equation (**21**) the function $f(\tau - t)$ is that portion of the curve shown in Fig. 4 and extending from t_m to t_r. It should be determined at a continuous voltage equal to the amplitude E_m of the alternating potential. This function will vary with the material of the dielectric, the temperature and humidity of the specimen, and the physical condition of the dielectric.

Equation (**21**) comprises the essence of the cause for the decrease of charge with the frequency of the applied potential. Indeed, the mere inspection of equation (**21**) shows that the value of Q is a function of the upper limit $\frac{T}{4}$. The higher the frequency, the smaller is T and consequently the smaller the value of the integrand. In equation (**21a**), the values of i_{cA}, i_{cB} . . . i_{cN} substituted from equation (**20a**) contain $f_A(\tau - t), f_B(\tau - t)$ . . . $f_N(\tau - t)$. These functions should be determined at continuous potentials of magnitudes equal to E_A, E_B . . . E_N.

C. The "Dielectric Permittivity" K of Solid Dielectrics

Imagine two condensers, No. I and No. II, of the same physical dimensions. Let the space between the plates of condenser No. I and condenser No. II be filled with a solid dielectric and vacuum, respectively. Let the charges acquired by condensers No. I and No. II, when each is submitted to the same potential, be Q_I and Q_{II}. Then the dielectric permittivity will be:

$$K = Q_I / Q_{II} \tag{22}$$

For continuous potentials:

$$K_1 = \frac{\int_0^{tr} i_c \, d t}{\int_0^{tr} i_c' \, d t} = \frac{\text{equation (9)}}{\int_0^{tr} i_c' \, d t} = \frac{\text{equation (9)}}{E K a / d} \tag{23}$$

For alternating potentials, where no instantaneous value exceeds the upper limit of the initial potential range:

$$K_1 = \frac{\text{equation (21)}}{\int_0^{T/4} i_c' (\cos \omega t) \, d t} = \frac{\text{eq. (21)}}{\text{eq. (45)}} \tag{24}$$

and for alternating potentials, where instantaneous values do exceed the upper limit of the initial potential range:

$$K_3 = \frac{\text{equation (21a)}}{\int_0^{T/4} i_c' (\cos \omega t) \, d t} = \frac{\text{eq. (21a)}}{\text{eq. (45)}} \tag{25}$$

The denominators in equations (23), (24), and (25) can be very easily computed; see Part III. The numerators are defined by equation (9) with the limits changed from 0 to t, and by equations (21) and (**21a**) respectively.

The definitions given above take account of all the factors which influence K; see discussions of equations (21) and (**21a**). Moreover, the values of K, determined from these equations will be different for the same material if f and G be changed. The "dielectric constant" is thus a very inappropriate term. A better appellation, "dielectric coefficient," has been suggested. This new name is here replaced by the more descriptive and shorter one, permittivity, adopted by some text books. The writer regrets that he has never met with this term in reading the literature.

E. The Energy Dissipated in Solid Dielectrics

1. *Causes of Energy Dissipation.*

The energy dissipated in solid dielectrics may be due to one or all of the following three clauses:

a. The resistance of a dielectric to the flow of current,

b. Dielectric hysteresis,

c. Dielectric viscosity.

No successful attempt has been made, so far, to separate the total energy loss into its three component parts. Moreover, the three sources of energy loss are not clearly defined. It will be our object, therefore, (1) to investigate the sources of these losses in the light of the established hypotheses; (2) to introduce definitions of the three types of energy loss; and (3) to devise means for the separation of the total energy dissipated into its three component parts.

2. *Sources of Energy Loss with Alternating Potentials.*

In view of the hypotheses established in Part I we shall consider separately the behavior of the three types of electrons in a dielectric subjected to alternating potentials.

a. **Perfectly Elastic Electrons.** When an alternating potential is applied to a dielectric, all the electrons are displaced from their neutral position of equilibrium. Those that are perfectly elastic will be displaced by a distance which may or may not be proportional, at every instant, to the instantaneous value of the impressed voltage. However, for this type of electrons, the same relation between the distance by which the electron is displaced and the instantaneous value of the applied potential exists no matter whether this distance be measured at increasing or decreasing values of potential. If δ is plotted as ordinate and $E_m \sin \omega t$ as abscissa, we get the curves shown in Fig. 11B.

Whether the curve is of the form (A) or (B) will depend entirely upon the characteristics of the individual electron. The interesting fact to remember is that the curve closes on itself and therefore no energy is lost.

b. **Perfectly Viscous Electrons.** The displacement of the viscous electrons gives a very different curve from the ones shown in Fig. 11B. Here the electron displays no elasticity; consequently, it continues to creep in the same direction irrespective of the instantaneous value of the impressed potential, provided that value maintains the same sign. As soon as the polarity of the applied voltage changes, the direction of creepage reverses. The distance covered by the creeping electron is at any instant directly proportional both to the instantaneous value of the applied potential and to the time through which that instantaneous value acts. We thus have for the displacement due to any potential $= E_m \sin \omega t$ and acting for an instant Δt:

$$\Delta \delta = h E_m \sin \omega t \, \Delta t$$

and for the total displacement attained during a time from 0 to t:

$$\delta_t = h E_m \int_0^t \sin \omega t \, d t = \frac{-h E_m}{\omega} \cos \omega t \qquad (31)$$

This curve is plotted in Fig. 11c. It can be best visualized by shifting the origin O to the point O'. The existence of ω in the denominator of equation (31) shows that δ_t is a function of the period of the impressed potential.

c. **Slightly Elastic or Partially Viscous Electrons.**

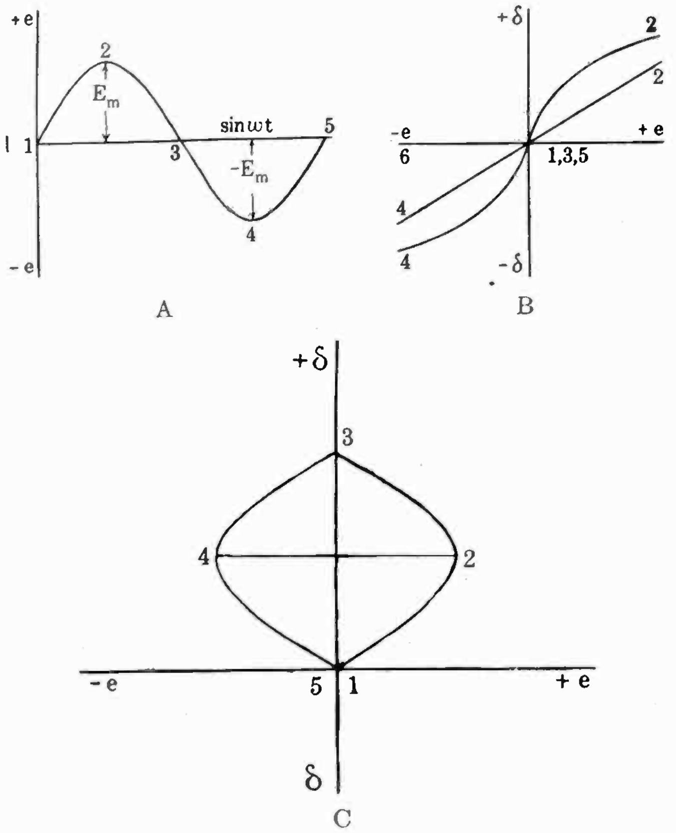

FIG. 11

A—A SINE WAVE OF VOLTAGE
B—VARIATION IN THE DISPLACEMENT OF A PERFECTLY ELASTIC ELECTRON WITH VOLTAGE
C—VARIATION IN THE DISPLACEMENT OF A PERFECTLY VISCOUS ELECTRON WITH VOLTAGE

In the case of the partially viscous electrons, the elasticity of their bonds furnishes them with enough resilience to rebound whenever the impressed potential suffers a decrease. The distance by which they rebound is a function of their elasticity, the value of the impressed voltage and the decrease suffered by that potential. The curve given in Fig. 12 is representative of one type of such a hysteresis loop. For other types of loops, the reader is referred to the very interesting work (54-21) wherein several loops are plotted with charge as abscissa against applied potential as ordinates.

d. **The Hystero-Viscosity Loop.** The hystero-viscosity loop (Fig. 12) may be determined for any dielectric as follows:

A continuous potential-gradient G_1 is impressed on the dielectric for a time t_{r1} and the charge Q_1, (see Fig. 4), acquired by the dielectric during the interval t_{r1} is measured. The charge density D_1 will then be:

$$D_1 = Q_1/a \qquad (32)$$

The gradient is next raised to G_2, the charge Q_2 acquired in the time 0 to t_{r2} is measured and D_2 computed. This process is repeated until the maximum gradient G_m, for which the loop is required, has been attained. We thus obtain the curve $0\,a$ (Fig. 12) which we shall call the "electrization curve" in analogy to the "magnetization curve."

Just as in the magnetization curve, the permeability at any field intensity is $\mu = B/H$, so here, the absolute permittivity K' of a dielectric at any voltage gradient G is:

$$K' = D/G \qquad (33)$$

The voltage gradient is next lowered to a value $G_n < G_m$. If G_n is low enough, *i. e.*, if $E_n < 2 E_p$, a current will flow in the reverse direction for a time t_n at which time its value becomes zero. This reverse current is

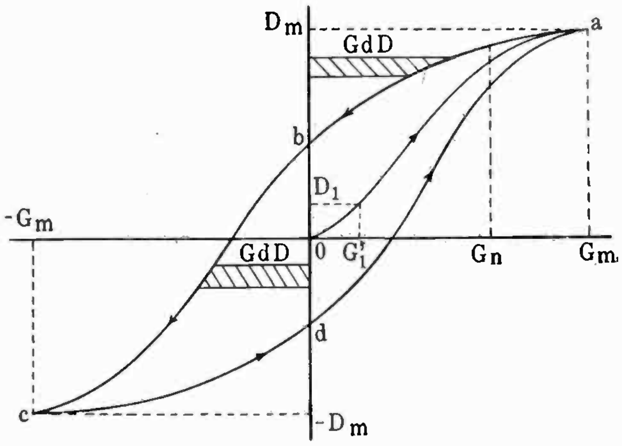

FIG. 12—A HYSTERO-VISCOSITY LOOP

due to the fact that, the polarization potential being in excess of the new impressed potential, some of the elastic electrons rebound to their original position, thereby allowing a part of the charge on the plates to recombine. Moreover, the recombined charge in the dielectric is exactly equal to the released charge. If we measure this recombined charge and subtract its value from Q_m, we obtain the charge Q_n which remains in the condenser at the gradient G_n. D_n will then be Q_n/a. By a similar process we may compute D_{n-1} at G_{n-1} . . . and D_0 at $G = 0$.

As the time element is of importance in determining this loop, ample time should be allowed for the viscous electrons to readjust themselves to each new state. Therefore, the time consumed in determining the curve $a\,b$ should be at least equal to that spent in ascertaining the curve $0\,a$. Moreover, the short circuit (at $G = 0$) should last long enough to allow all electrons which possess any degree of elasticity at all to rebound to their normal position. This time cannot be fixed for it depends upon the type of material experimented on.

The length of the line 0 b represents the residual charge due to purely viscous electrons. These electrons, being utterly devoid of resilience, need a *coercive force* in the opposite direction to move them to their original neutral position.

The polarity of the applied potential is now reversed at the point b, and the density of charge D, corresponding to any gradient G, measured, as indicated above, until the negative maximum gradient $(-G_m)$ is attained. We thus obtain the curve $b\,c$. The curve $c\,d$ is obtained similarly to the curve $a\,b$ by successively increasing the potential from $(-G_m)$ to zero.

Finally the curve $d\,a$ is plotted from data observed, as described above, by successively increasing the potential from zero to G_m.

3. Definitions and Separation of Dielectric Losses.

a. **The Resistance Loss** (W_r). The loss per unit volume, per cycle due to the resistance of a dielectric to the passage of current, at alternating potentials, shall be defined as follows:

1. For potentials whose amplitudes exceed the upper limit E_A of the initial potential range A,

$$W_{r1} = 4 \text{ (equation 5)}/V \quad \text{Joules/cm.}^3 \qquad (34a)$$

2. For potentials whose amplitudes *do not* exceed the upper limit E_A of the initial potential range A,

$$W_r = 4 \text{ (equation 8)}/V \quad \text{Joules/cm.}^3 \qquad (34b)$$

b. **The Total Loss** (W_D) dissipated per unit volume per cycle shall be defined as the total loss, measured by known methods, divided by the volume of the dielectric, divided by the number of cycles made during the time of running the test.

$$W_D = \text{(Measured Loss per cycle)}/V \quad \text{Joules/cm.}^3 \qquad (35)$$

For the same amplitude of applied potential, W_D will decrease as the frequency is increased, until a frequency f' is reached beyond which the loss per cycle is constant and independent of the frequency. This particular value of W_D will be defined as:

$$W_{Df'} = \text{(Measured constant loss per cycle)}/V \quad \text{Joules/cm.}^3$$

c. **The Loss due to Hysteresis** (W_h): The hysteresis loss per unit volume per cycle at any frequency shall be defined as follows:

1. For potentials whose amplitudes exceed the upper limit E_A of the initial potential range A,

$$W_h = \text{(equation (36))} - \text{(equation (34a)) Joules/cm.} \qquad (37a)$$

2. For potentials whose amplitudes do not exceed the upper limit E_A of the initial potential range A,

$$W_h = \text{(equation (36))} - \text{(equation (34b)) Joules/cm.}^3 \qquad (37b)$$

d. **The Losses due to Viscosity** (W_v): Enegry dissipated per unit volume per cycle due to viscosity shall be defined as:

$$W_v = \text{(equation (35))} - \text{(equation (36)) Joules/cm.}^3 \qquad (38)$$

It must be remembered that the above equations hold true only under constant conditions of voltage gradient, temperature, humidity, etc. The only factors here eliminated are time and frequency.

NOTATIONS

Symbol	Quantity	Units
a	Area	Cm².
c	Chemical composition of a dielectric	
C	Capacitance (Permittance)	Farads
c	(Subscript) charge	
d	Thickness	Cm.
d	(Subscript) discharge	
D_c, D_d	Charge and discharge density	Coulombs/cm.²
E	Voltage (Continuous or effective)	Volts
e	Voltage, instantaneous	Volts
f	Frequency	Cycles/sec.
G	Voltage gradient	Volts/cm.
H	Humidity	= Per cent
I	Current, continuous or effective	Amperes
i	Current, instantaneous	Amperes
K	Dielectric constant (Permittance)	Numeral
M	Material of electrodes	
N	Refractive index; any number	
p	Physical condition of a dielectric	
P	Mechanical pressure on a dielectric	kg./cm.³
p	(Subscript) Polarization thus E_p = polarization e. m. f.	
Q_c	Charge	Coulombs
Q_d	Discharge	Coulombs
R	Resistance	Ohms
℞	Ionizing radiations	
s	Shape of electrodes	
S	Elastance $= i/C$	Darafs.
s	(Subscript) strength thus G_s = dielectric strength	
t,	Time	Sec.
T	Temperature	Deg. Abs.
U	Current density	Amps./cm.²
V	Volume	Cu. cm.
W	Energy	Watt-sec.
W'	Energy density	watt. sec/cu. cm.
ρ	Resistivity	mho/cm.³
γ	Conductivity	ohm/cm.³
σ	Elasticity	Darafs.
θ ϕ	Angles	Deg.
ω	$2\pi f$ (Angular velocity)	radians/sec.
$A, B, \ldots S$	(Subscripts) Limits of ranges	
$A, B \ldots S$	(Not subscripts) Ranges.	

COLOR BY WIRE

It has been reported that a new invention at the Massachusetts Institute of Technology makes possible the matching of colors by wire or radio. Exact reproductions of any shade can be made without the possibility of visual error, thus advancing the industries from dependence upon the human eye.

The color specimen is placed in a holder close to a high-power electric lamp. Light is alternately reflected from it and from a block of magnesium carbonate, the whitest of the world's substances, and variation of reflection from these two surfaces is registered by a photoelectric cell and transmitted in electrical impulses by either wire or radio.—*Interstate News,* Nov. 1, 1927, Indianapolis, Ind.

Abridgment of

Printing Telegraphs on Non-Loaded Ocean Cables

BY HERBERT ANGEL[1]

Associate, A. I. E. E.

Synopsis.—This paper discusses the application of printing telegraphs to ocean cable operation. Reference is made to various improvements in apparatus and operation, tending toward increased output, and the effect of the application of these improvements from the laying of the first cable to the present time. Telegraph codes and their relation to speed and their applicability to printer operation are also discussed.

Transmission methods, shaping of the signals, variable lag and the effect of earth currents are also described in the paper. Manual, semi-automatic and full automatic operation of long ocean cables are covered briefly. The characteristics and advantages of regenerative repeaters are pointed out and the operation of printers on cables described.

* * * * *

History

Since the laying of the first successful ocean cable between Heart's Content, Newfoundland, and Valentia, Ireland, cable engineers have worked to increase the output or speed by improving the terminal apparatus and by the use of more efficient operating methods.

The progress made in cable operation since the early cables were laid will be more readily appreciated if we note the various steps of increased output of a given cable, laid approximately 50 years ago and which is still in service.

The original speed or output of this type cable when operated with the mirror galvanometer was about 70 letters per minute. By the use of the siphon recorder this speed was increased to 80 letters per minute or 13.3 words per minute. With the application of the duplex principle, by which two messages are sent at the same time, one in each direction, the output was practically doubled to 160 letters per minute. Then followed the introduction of the automatic transmitter raising it to about 220 letters per minute. The addition of the magnifier further increased the output to about 300 letters per minute. With printer operation the output of this cable has been increased to something like 375 letters per minute.

From this review, it will be seen that the original output of this cable of 70 letters per minute has been increased over 500 per cent, all of which has been brought about by the development of transmitting and receiving apparatus.

Object of Printer Operation on Ocean Cables

There were at least two objects in view in applying a printing telegraph system to ocean cables. One being to further increase the output of the cable and the other to make the operation wholly automatic.

Up to the time of introduction of the cable printer, cable operation might be considered as semi-automatic; that is, while the transmission was automatic the reception was not, as it was necessary that the siphon recorder signals be manually translated by skilled operators, whereas with printer operation the signals are translated mechanically and printed on a page or tape as may be desired.

Problem of Transmission

Before discussing the actual work of the printing system it may be well to consider first the problem of transmission. This being fundamental it should be clearly understood in order to more fully appreciate what follows. In all systems of wire communication a necessary element is the code of signals or telegraphic alphabet to be used for transmitting the message.

In this discussion the term *code* may be interpreted as a series of predetermined combinations of one or more electrical impulses or time units. These code combinations must be transmitted over the cable and translated into the letters of the alphabet at the receiving end. The selection of the code, (for there are several kinds), determines the number of letters or words per minute which can be transmitted over a cable. The reason for this being that different codes have different time unit lengths. Not only do different codes vary in time unit length, but a particular code may in itself have combinations of variable time unit lengths.

For example, the international Morse code has an average length of about eight and one-half time units per combination or character, some of the combinations containing only four units and some twenty units. In the cable Morse code, which also has combinations of variable length, the average time unit length is 3.7 units. Such codes may be classed as non-uniform codes. Then there are the uniform codes in which each combination is of equal length such as the Baudot code of five time units and the Cook code of three units, so that we have at least four kinds of codes available for transmitting intelligence over the cable.

The next logical step is to determine the best code to use for the work to be undertaken. For this purpose reference will be made to the code used on the cable

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Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 21-24, 1927. Complete copies upon request.

selected for this comparison and the speed at which the cable is operated. The speed of a cable is usually referred to in terms of the number of letters that can be transmitted and recorded in one minute. This is determined in practise by finding the highest rate of speed or frequency at which alternating current, or, as termed in cable practise, reversals of current can be transmitted over the cable and that will arrive at the receiving end with sufficient amplitude to properly operate or deflect the delicate recording instrument. This rate of speed is termed the working fundamental frequency. It does not, however, mean it to be the maximum frequency of the cable which is probably much greater.

With the code originally used on this particular cable as a basis, it can be determined which code should be used for printer operation, bearing in mind that the printer must necessarily yield an output as good as, or preferably better than the cable Morse code.

Codes

Previous to the installation of the printer, this particular cable was being operated at the rate of 150 letters per minute using the cable Morse code of 3.7 units. This means that the maximum number of time units that can in practise be transmitted over this cable is $150 \times 3.7 = 555$ units, which reduced to terms of fundamental frequency is $\frac{555}{60 \times 2}$ or 4.6 cycles per second. The output in letters per minute for any stated code is found by dividing the known speed of a given cable in time units per minute, by the figure representing the average number of units of the code under consideration.

Applying this formula to the particular cable just mentioned, the speed of which was 555 time units per minute, the output in letters per minute for the different codes would be:

International (Two-current non-uniform code)	$\frac{555}{8.5}$	= 65.3 letters per minute
Cable Morse (Three-current non-uniform code)	$\frac{555}{3.7}$	= 150 letters per m nute
Baudot (Two-current uniform code)	$\frac{555}{5}$	= 111 letters per minute
Cooke (Three-current uniform code)	$\frac{555}{3}$	= 185 letters per minute

Of the four codes available for printer operation, it is obvious that the International code gives too low an output and may therefore be eliminated for this reason and also because a non-uniform code requires a more complex printer mechanism than does a uniform code. The Cable Morse, or three-current code, may also be eliminated because of its non-uniformity.

This leaves two codes for consideration, the Baudot five-unit and the Cooke three-unit. The five-unit code was chosen for the first experiment.

The question may arise as to why the longer code of the two was selected if increased output is to be a factor in the development of a printing system. The answer is that while both the Baudot five-unit code and the Cooke three-unit code are uniform so far as their unit lengths are concerned, there is still another important difference. The Baudot is a two-current code while the Cooke is a three-current code. The two-current code is made up of positive and negative impulses and the three-current code of positive, negative and zero impulses. The two-current code is more desirable for printer operation than the three-current code because it makes for greater simplicity of mechanism.

A further and important reason for selecting the two-current Baudot code of five units is that it is adaptable to a method of transmission, discussed later in the paper, which permits the actual doubling of the number of letters per minute shown in the above table of speeds. In this case, we have the apparent paradox of the longer code giving a higher output than the shorter code. The three-current code is not adaptable to this method of transmission.

Notwithstanding these differences, however, both the Baudot and Cooke codes were tried out in actual service for purposes of comparison.

The first cable printer experiment with the five-unit code was tried over an ocean cable previous to the outbreak of the World War. The results of this experiment were considered satisfactory but a continuation of the test was interrupted due to the war's outbreak and the investigation was then confined to the laboratory. The second ocean cable experiment was tried out in 1916, this was with the three-unit code. The results of this experiment were also considered satisfactory and this system was operated under regular traffic conditions between Ireland and Newfoundland during 1919 and 1920. Later the investigation led back to the five-unit code which was also operated between Ireland and Newfoundland and has been in continuous operation for several years.

Principle of Ocean Cable Printing Telegraph System

A printing telegraph system applied to an ocean cable does not necessarily introduce new features with respect to the actual operation of the cable itself. It merely provides an organization of apparatus for transmitting the signals representing the letters of the alphabet and for causing them to be automatically translated into printed characters at the receiving end of the cable. Heretofore, this translation has been the work of the skilled operator.

Basis of the System

The basis of the cable printing telegraph system is a selective sending and receiving apparatus synchronously operated.

The sending apparatus includes a perforating machine resembling a typewriter keyboard which is used by the operator for preparing the message on a strip of paper tape, a constant-speed distributor or transmitter, driven by a tuning or driving fork, combined so as to select and transmit in proper sequence the code or letter combinations set up in the strip of tape.

The receiving apparatus includes a constant-speed distributor, also driven by a fork, and an automatic typewriter or printer, combined to select automatically the received signals or letters and cause them to operate the type bars of the automatic printer.

In Fig. 1 is shown schematically a single channel printing system. In the transmitter at the upper left of the figure, T is the perforated strip of tape which feeds continuously through the transmitter at a constant speed.

The five reciprocating pins or rods $U\,P$ of the transmitter are operated seriatem by the five cams on the cam shaft $C\,S$. When a pin finds a hole in the tape it rises through the tape and rocks the pole-changer $P\,C$ to its marking contact $M\,C$. The absence of a hole causes it to be rocked to its spacing contact $S\,C$. The pins $U\,P$ which rise one after another are slightly staggered to compensate for the moving tape. The pole-changer operates a transmitting relay A, through circuit $C\,T$, which in turn operates the regular cable sending-on relays B that transmit into the cable through the sending condenser K. At the receiving end of the cable in the cross circuit of the duplex bridge are located the magnifier and cable relay. These instruments are comparatively sensitive to small currents, the magnifier requiring only five or six microamperes to operate it and the relay something in the order of 50 to 80 microamperes to give a good working signal. The contacts of the relay are shown connected to two local relays C which operate into the printer circuit.

From here the circuit extends through $C\,X$ and $C\,W$ into the two control relays $C\,R^1$ and $C\,R^2$ and the printer relay $P\,R$ of the printer circuit, returning to the battery source at $C\,Z$.

The two control relays $C\,R^1$, $C\,R^2$ control the fork through magnet F^1 and keep it vibrating in synchronism and in phase with the distant transmitter. The driving fork in turn operates a step-by-step distributor through its contacts $F\,T^1$ and $F\,M^1$ and the distributor magnet. The magnet rotates a cam shaft containing a series of cams, C, which raise the levers $A1$ to $A6$ in sequence. These in turn close the selecting contacts 1 to 5 of the printer selecting magnets.

This arrangement of sending and receiving apparatus, operating synchronously, causes the five selecting contacts of the receiving apparatus to function in step with the five reciprocating pins of the transmitter, so that an impulse transmitted through the medium of any one pin of the transmitter will be received on the corresponding selecting contact of the receiving distributor. Mounted on the shaft with the five cams referred to is a sixth cam, the purpose of which is to cause the printer to function after the five selecting cams have completed their cycle.

If we keep in mind the fact that the transmitter and receiving distributor are running in exact step, it will be quite simple to follow the train of events which occur to bring about the printing of any given character. We shall assume that the tape is being fed into the transmitter and that the holes for the letter O are just passing over the transmitter pins. In this case, the fourth and fifth pins become operative and rock the pole-changer to its marking contact $M\,C$ for a two-unit time length. The marking sending-on relay then operates and transmits negative or selecting current to the cable which in turn deflects the magnifier at the receiving end and correspondingly the cable relay to its marking contact for two units of time.

In this case the local marking relay, the control relay $C\,R^1$ and printer relay $P\,R$ are operated by the cable relay and therefore move their tongues to their marking contacts M. The control relay $C\,R^2$ moves its tongue to its spacing contact because its winding is in opposite direction to that of relay $C\,R^1$. Neglecting the operation of the intermediate control relays we pass on to the printer relay $P\,R$ which as stated was operated to its marking contact by the cable relay. From here the current path is through the selecting contacts 4 and 5 of the distributor, which correspondingly closed in step with the pins of the transmitter, causing the operation of selecting magnets 4 and 5 of the printer which control the O type bar.

The current which operates the selecting magnets has its source from the middle point of the potentiometer $R^1\,R^2$, condenser K^1 fork time F and contact $F\,M$ (when closed), resistance $R\,S^2$, tongue T of printer relay $P\,R$, contact M, resistance $R\,S$, to the common connection of the upper distributor contacts $C\,C$, thence through the corresponding lower springs of the fourth and fifth selecting contacts to their associated printer selector magnets 4 and 5.

While the above description discloses in simple form the operation of a one-channel printer system as applied to ocean cables, it does not attempt to describe the operation in its entirety.

There are at least two features in connection with this cable printing system which may be considered as outstanding and to which reference should be made.

One feature is the relatively low fundamental line frequency required for a given output in words per minute as compared with so-called five-unit single-channel printing systems used in land-line operation. The reason for this is what may be called "continuous transmission"—that is, the five-unit code impulses of the cable printing system are transmitted successively without any additional intervening impulses being sent between the fifth and first impulse. Up to the time that the cable printer was developed, the land-line single-channel systems transmitted seven impulses per revolution of the distributor. This lengthened the code to seven time units, five units being used for the code and two units for synchronizing and overlapping time between the fifth and first impulses. The difference

yield an output better than the shorter cable Morse code. This is brought about in the following manner:

Referring to the paragraph under Codes, it was shown that the practical fundamental frequency of the cable in question was 4.6 cycles per second or 555 half waves per minute. Also that these waves or signals in cable

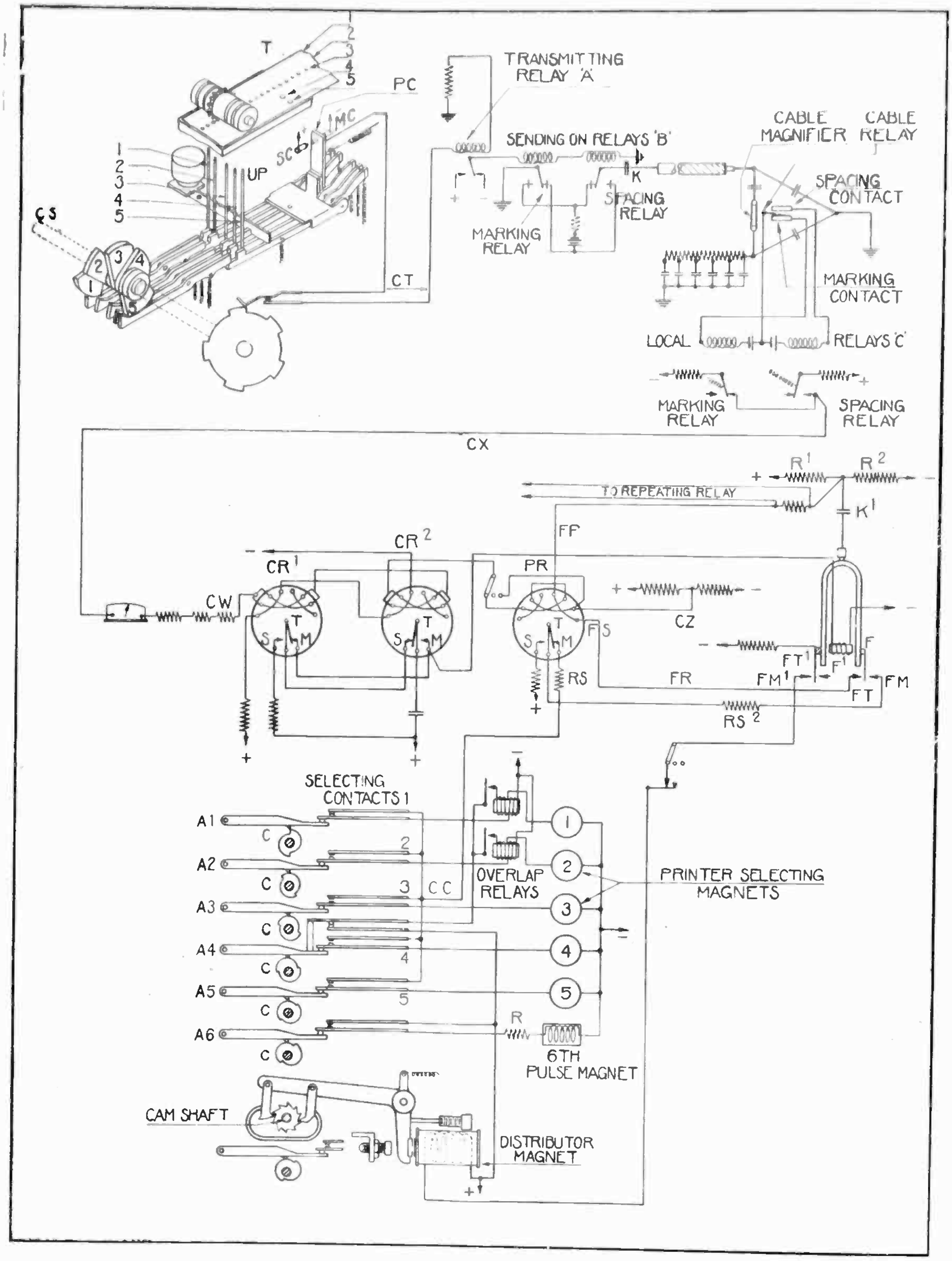

Fig. 1—Schematic Diagram of Cable Printer Circuits

between 5 and 7 units gives the cable printing system about 1.5 times more letters at any given frequency.

The other feature was earlier referred to in this paper as a method of transmission by which it becomes possible to double the output of a five-unit code printer system. That is to say, the five-unit code is made to

Morse operation must be of sufficient amplitude to properly operate the delicate cable relay. Further it was shown that at the above frequency the cable Morse yielded 150 letters per minute and the five-unit code 111 letters per minute.

Heretofore, it has been the practise in cable work, to increase the speed of transmission only to such a point that the attenuation of the arrival signals does not decrease the amplitude below that required to properly operate the delicate receiving relay. In this method of transmission when applying printer operation to long cables, increased speed is brought about by taking advantage of the attenuation.[2]

This is accomplished by increasing the rate of transmission to practically twice the rate of the cable Morse speed. In this case the fundamental waves or alternations are attenuated to such an extent that they are practically undiscernable at the receiving end of the cable and, of course, cease to deflect the cable relay.

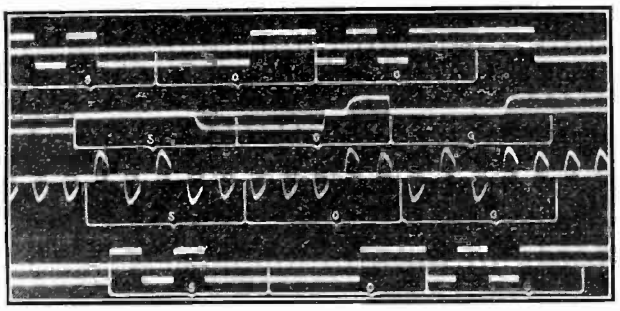

Fig. 2— Oscillogram of Cable Printer Signals

To all intents and purposes these waves arrive as zero impulses similar to zero impulses as employed in cable Morse code operation. A wave of two-unit length, however, will now arrive with the same amplitude and duration as a single wave in cable Morse operation.

It will be understood from this then that a single wave or a series of alternating waves will arrive at the distant end of the cable as zero waves and that the cable relay will now be deflected only by a wave two or more units in length. In the case of the non-arrival of the single waves, a local impulse or wave producer is employed to fill in the missing impulses and to reconstruct or regenerate the received signals so that they resemble the original transmitted signal.[3]

This wave producer forms a part of the printer regenerative circuit. It is shown theoretically in Fig. 1 at *F*, *F T*, *F R*, *F S* and *F P* to potentiometer $R^1 R^2$. This circuit is through an auxiliary winding of the printer relay which reverses the relay tongue to its opposite contact when the cable relay is deflected to the "no-man's land" or zero position and automatically fills in locally the reversal waves which fail to arrive.

The transmitted, received, and regenerated singals are shown in Fig. 2, in which are depicted the combinations of impulses or waves for the characters *S O G*.

A = the signals from the contacts of the transmitter.

B = the signals from the contacts of the cable local relays showing a straight zero line where the single waves are missing.

C = the signals from the cable local relays (*B* signals) picked off by the regenerating action of the printer apparatus and the missing impulses filled in.

D = the *B* and *C* signals reassembled and regenerated into their original shape as at *A*.

A cable printing system has now been shown, employing a five-unit two-current code by which can be transmitted over this particular cable practically twice as many impulses as can be sent with the three-current cable Morse system; namely, 555 × 2 or 1110 impulses per minute. Correspondingly a greater number of letters per minute are transmitted, *viz.*; $\frac{1110}{5}$ or 222 letters, as compared with 150 letters obtained with the cable Morse code.

The Cooke three-current code and the cable Morse three-current code cannot be used in the manner just described because a zero current element forms part of these codes. Hence, there would be no way to differentiate between the zero forming part of the code and the zero resulting from the suppression of the single waves.

As already stated in the earlier part of this paper, the printing system was successfully operated over an ocean cable between Ireland and Newfoundland. This

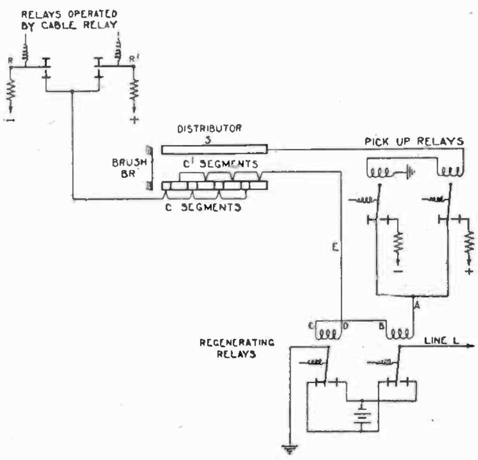

Fig. 2A—Schematic Diagram of Rotary Repeater for Cable Morse Code Operation

was not, however, the final solution of printer application to ocean cables. The next problem was to extend the system so that it would operate directly between the two terminals of a cable circuit, as between London and New York.

This problem was met, and the solution provided, by the development of the regenerative repeater. A regenerative repeater consists of apparatus which, to all intents and purposes, functions similarly to the printing system which we have just discussed.

It must be capable of mending, as it were, or reconstructing the more or less distorted signals received at

2. This principle was first suggested by K. Gulstad in 1898, and was applied to the operation of comparatively short sections of cable.

3. In 1913 Walter Judd and Benjamin Davies, of England, invented a method for doing this and were the first to apply this principle to long ocean cables.

the end of a land line or cable and retransmitting them into the next section as new or regenerated signals.

There are at least two kinds of regenerative repeaters, one known as the rotary, and the other, as the fork repeater. Such a repeater consists of synchronous apparatus arranged to pick out the best portion of the arrival signal and reconstruct it so that it is identical with its original shape.

This type of repeater permits direct operation between terminals separated by great distances. As an example of its efficiency, a direct circuit with printer operation was successfully worked between London and San Francisco. This circuit was about 7400 mi. in length including 2600 miles of submarine cable and 4800 miles of open line. There were 21 repeaters in the circuit, five being regenerators between New York and London and the remainder being standard land line repeaters. Fig. 3 shows the magnitude of the London-San Francisco circuit.

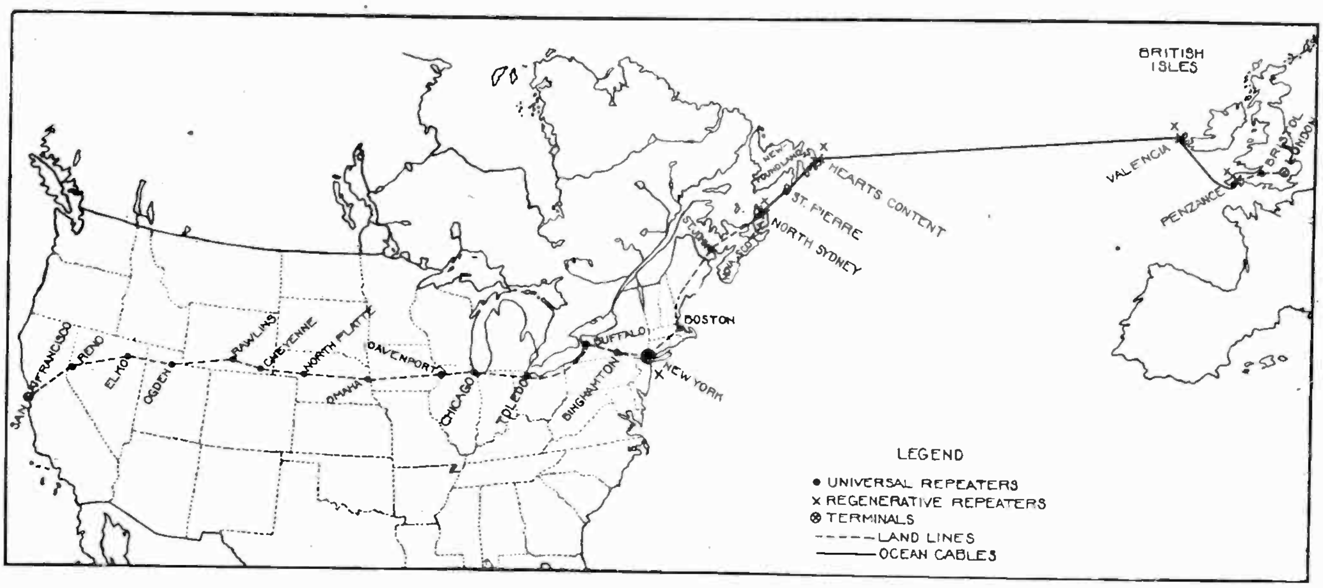

Fig. 3—Map of London—San Francisco Circuit

Regenerative Repeaters

Regenerative repeaters have been in use on the Western Union cable circuits for a number of years and practically all of its old type ocean cables are operated as direct through circuits between London and New York.

In addition to the type of regenerator disclosed in Fig. 1 in connection with the printer, another type of regenerator is shown in Fig. 2A. Here the regenerator is shown as adapted for cable code. The segments C pick up a portion of the received signal from the relays R and R^1 and transmit it into the biased pick-up relays via brush $B\ R$ and ring S. These relays in turn operate the biased regenerating relays via A, B, C, D, E, segments C^1, ring S and the windings of the pick-up relays. The regenerative relays transmit the new signal into line L.

Reception of Signals Over Ocean Cables

The quality or definition of the received signals has such a direct bearing on the operation of printing telegraphs over ocean cables that it necessarily becomes of primary importance. Much has been written about this particular subject, and cable engineers have devoted considerable time towards improving the definition of cable signals. The recent new type of permalloy loaded cable developed by the Western Electric Company is a radical departure in cable design and has considerably increased the cable output above that of the best cables of the standard type.

Reception of cable signals in its final analysis simmers down to "signal shape."

As an illustration of the relative difference between the shape of the transmitted and received signals, a group of signals is shown in Fig. 4, in which A represents the transmitted signals and B, the received signals. It is this difference between the sent and received signals which must be corrected for automatic working.

In the discussion of the reception of cable signals, at least four characteristic effects met with in every day working are referred to, namely:

1. The "swaying effect" caused by earth currents.
2. The "falling-away effect" of certain signals due to the charging up process of the cable and its associated condensers.
3. The "wandering zero effect."
4. The "variable lag effect."

The latter two effects are the result of a condition in the cable brought about by the transmission of impulses having variable lengths.

To illustrate the means for counteracting these different effects, a schematic diagram of a cable circuit as used for printer operation is represented in Fig. 5 in which, M is the Heurtley hot wire magnifier and $C\ R$, the cable relay.[4]

4. There are at least three types of cable relays; the Drum relay of S. G. Brown, England, Gold Wire Relay of A. Muirhead, England, Antenna Relay of Eastern Telegraph Company, England.

In the figure it is shown that the cable is operated with unshunted sending and receiving condensers. The condensers serve the purpose of preventing, to a certain extent, the flow of the relatively low-frequency earth currents which are more or less prevalent in transatlantic cables.

The inductance shunt in Fig. 5 serves a two-fold purpose. It helps to improve the definition of the received signal and to counteract the effect of "wandering zero." The correction or shaping circuit in Fig. 5

FIG. 4—SHOWING DIFFERENCE BETWEEN SENT AND RECEIVED SIGNALS

is for counteracting the "falling away effect" of the arrival signals as they are passed into the cable relay and for transforming the curved waves into square-topped signals.[5]

In Fig. 6 is shown a group of signals in which A represents the original transmitted signals and B, the received signals as they pass into the cable relay from the magnifier. For the purpose of illustrating the "wandering zero effect" and the "falling-away effect" upon these signals, a zero line has been drawn through the curves to show how the zero portions of the curves have wandered from true zero at X, X^1.

Record C shows the signals from the contacts of the cable local relays before the correction has been ap-

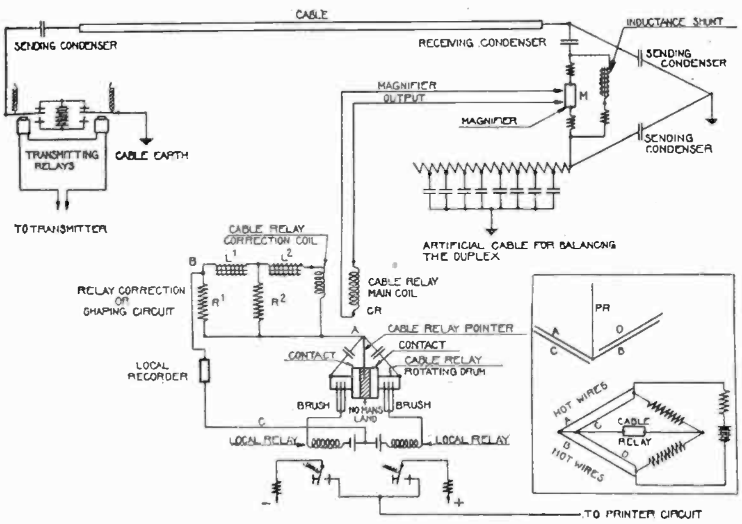

FIG. 5—SCHEMATIC DIAGRAM OF CABLE CIRCUIT

plied. Record D shows the signals with the correction circuit applied, and illustrates how it has upheld the current waves and straightened out the zero waves.

VARIABLE LAG

Variable lag is only troublesome in connection with the reception of cable signals in their relation to synchronous automatic operation. In ordinary siphon recorder operation, it is not apparent. Its effect is to shift or displace the arrived signal so that it does not arrive in the exact location assigned to it on the receiving distributor. As a matter of fact, in extreme

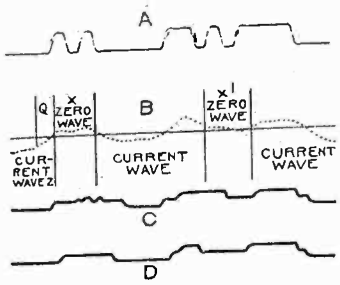

FIG. 6—SHOWING UNCORRECTED AND CORRECTED SIGNALS

cases it has been found that the signals are displaced about 35 per cent of their unit length. Variable lag is the result of irregular or non-uniform transmission. A regular or uniform transmission is one in which continuous alternations or reversals of current of equal amplitude and duration are sent into the cable, and if the alternate half waves be free from bias or other defects, the electrical condition of the cable remains constant and the waves arrive in exact phase with the corresponding segments of the receiving distributor. Any deviation from this kind of transmission produces a variable condition in the cable, and the effects of shifting lag become evident, resulting in the wave crests appearing at indefinite points on the receiving distributor.

The difference between arrival signals composed of alternating or equal length signals and unequal length signals, is shown in the groups of signals in Fig. 7 in which A and B represent the sent and received alternating or equal length signals and C and D the sent and received signals of unequal length. It is obvious that the unequal length signals arrive in a somewhat disorderly shape, as indicated in D at X, where some of the waves have failed to cross the zero line and others failed to reach the zero line.

To counteract or correct the shifting effect of cable signals, several methods are employed. One method,

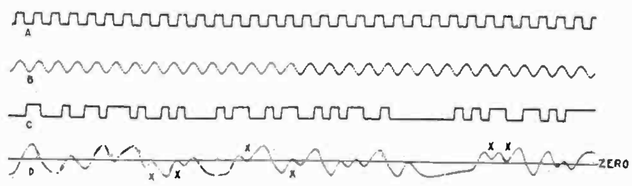

FIG. 7—SHOWING SIGNALS OF EQUAL AND UNEQUAL LENGTH

used in all synchronous telegraph systems is to shorten the length of the receiving segments with respect to the sending segments. To illustrate this method of lag correction, two developed distributor rings are shown in Fig. 8. In this case a single transmitted time unit or half wave occupies a segment of 72 deg. of the

5. This method of signal shaping was invented by S. G. Brown, of England.

sending distributor face plate, which is shown cut into five equal segments. From the figure it is obvious that the wave *A* must shift forward or backward approximately 50 per cent of its length before it will encroach upon the receiving segments $R S^2$ or $R S^4$. While this counteracts the effect of the variable lag, it does not

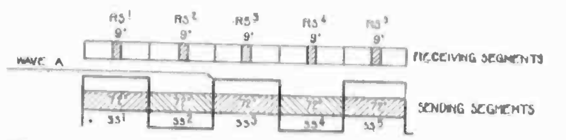

Fig. 8—Theoretical Diagram Showing the Best Position of the Receiving Segments with Respect to the Transmitted Wave

eliminate it. It must be dealt with at the transmission end of the circuit.

With this in mind, there have been devised various ways for transmitting cable signals, the object being to approach as nearly as possible an alternating current form of transmission. A modification of this method of transmission known as the "suppressed transmission,"

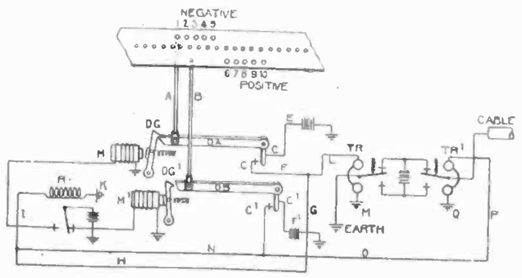

Fig. 9—Transmitting Connections for Suppressed Transmission. Earthing Method

was developed, whereby the code characters are transmitted in the form of broken alternating waves or reversals.

This is by far the best form of cable transmission yet presented and keeps the cable in an even state, counteracting or reducing so far as possible the variable lag. It is not being used at present on account of its

Fig. 10—Showing Difference Between Standard and Suppressed Transmission. Earthing Method

apparent limitations, as to speed of operation, but further investigations are being made with it.

Operation of Suppressed Transmission—Earthing Method

In Fig. 9 is shown a schematic diagram of one of several methods used for this kind of transmission. The transmitting circuit is so arranged that if two or any greater number of unit impulses of like polarity come in succession, only the first unit is sent into the cable and the cable is then earthed for the remainder of the successive units. For example, in the figure, it is assumed that the tape is feeding towards the left until hole 1 is presented to oscillating pin *A*.

As pin *A* rises through the tape, contacts *C*, *C* are closed energizing relay *R* via *E*, *C*, *C*, *F*, *G*, *H*, *I*, *R*, *K*, in a right direction. The closing of contacts *C*, *C* causes the latch magnet *M* to be deenergized through the contacts of relay *R*. This causes the latch *D G* of latch magnet *M* to fall into the path of the oscillating lever *O A* connected to pin *A*. As oscillating pin *A* is

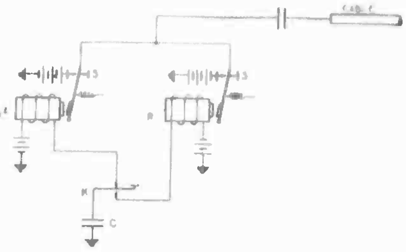

Fig. 11—Transmitting Connections for Suppressed Transmission. Insulating Method

withdrawn from the hole number 1, it is prevented from further rising by the engagement of the oscillating lever *O A* with the latch *D G* as shown.

At the moment contacts, *C*, *C* closed, transmitting relay *T R* closed via *E*, *C*, *C*, *F*, *L*, *M* and transmitted one time unit of negative current to the cable, then

Fig. 12—Showing Difference Between Standard and Suppressed Transmission. Insulating Method

when contacts *C*, *C* opened, transmitting relay *T R* returned to its upper contact and earthed the cable for the remaining units, 2, 3, 4, 5. The action of oscillating pin *B* is identically the same as that of *A*; in this case, however, one positive unit is transmitted by transmitting relay $T R^1$ via F^1, C^1, C^1, *O*, *P*, *Q* and the cable earthed for the remaining units 7, 8, 9, 10.

Fig. 10 illustrates the suppressed earthing method

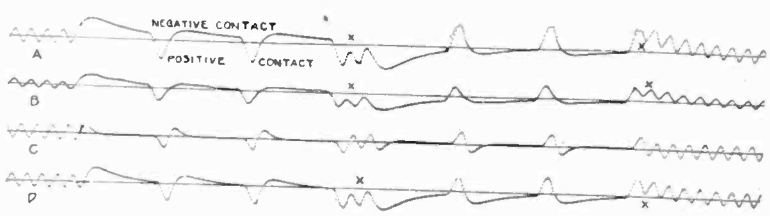

Fig. 13—Showing Received Signals Produced by Different Methods of Transmission

of transmission in which *A* represents signals transmitted as blocks and *B* the signals with all but the first unit suppressed and the cable earthed during the time of suppression.

Suppressed Transmission-Insulating Method

Another form of transmission tried out to counteract the variable lag effect is a "suppressed transmission" in which the cable is insulated instead of being earthed,[6]

6. First tried by Mr. Pierre Picard in 1898.

Fig. 11 depicts a simplified form of the transmitting circuit used for this kind of transmission. Depressing K operates relay R^1 and raising K operates relay R^2. The condenser C is adjusted to hold either relay closed for the duration of one time unit only, then when the relay tongue returns to its contact S the cable is insulated for the remaining length of the signal.

Fig. 12 illustrates the suppressed insulating method of transmission in which A represents the standard block signals and B the suppressed signals with all but the first unit suppressed and the cable insulated during the time of suppression.

Among other forms of transmission suggested were the unbroken or continuous alternating current transmission[7] employing three amplitudes, and curbed transmission.

To illustrate the characteristic cable effects on the received signals produced by some of the transmitting methods four groups of received signals are shown in Fig. 13 in which A represents received signals from block transmission, B curbed transmission, C suppressed transmission earthing method, and D, suppressed transmission insulating method. The zero line running through the signals shows in the cases of A, B and D that some of the wave crests which should have arrived on a negative contact have actually drifted to a positive contact and vice versa as indicated at X. In the case of C, all of the wave crests arrived on their respective contacts.

Shunted Condensers

In discussing the various methods of transmission and the reception of cable signals, the cable circuit represented in Fig. 5, shows the cable to be operated with unshunted sending and receiving condensers. The reason, as already stated, for using unshunted condensers is to prevent the flow of the low-frequency earth currents, more or less prevalent in transatlantic cables. So far as signal shape is concerned, it seems to be generally accepted that signal shape is better when the condensers are shunted.

Abridgment of GRAPHICAL DETERMINATION OF MAGNETIC FIELDS THEORETICAL CONSIDERATIONS

By A. R. Stevenson, Jr.* and R. H. Park*
Associate, A. I. E. E. Non-member

Three papers on the general subject, "Graphical Determination of Magnetic Fields," are being presented simultaneously to cover three phases of the subject: 1. Theoretical Considerations, 2. Comparison of Calculations and Tests, by E. E. Johnson and C. H. Green, 3. Practical Applications to Salient-Pole Synchronous Machine Design, by R. W. Wieseman. In the complete paper, which is the first of this series, the authors have reviewed the history of the subject, have briefly stated the ordinary rules for plotting magnetic flux in air and in current-carrying copper, have developed additional rules for checking the accuracy of field plots, and have given theoretical methods for mathematically calculating the distribution of field in certain cases commonly encountered in practise.

The authors have called attention to the great value of the mathematical work by the German engineer, Rogowski, and the graphical methods by the French engineer, Lehmann. These German and French articles contain the only extensive practical applications of the plotting of magnetic fields in current-carrying regions with which the present authors are familiar. Since it is much more difficult to plot fields in current-carrying regions, and since the majority of readers are less familiar with this phase of the subject, the greater part of the first paper, "Theoretical Considerations," is devoted to a study of such fields. As special examples, the mathematical solutions for the magnetic field between the poles of a salient-pole alternator and the magnetic field in a circular conductor in a circular slot are given in Parts I and III, respectively, of this first paper. Part II of the first paper contains a set of theorems which deal with various questions which have arisen while studying this subject—such as the proof that there is no refraction of the lines of force at a copper-air boundary, but a change of curvature when a line of force crosses such a boundary; and a general law for checking any field plot by the relation of the magnetic intensity and its rate of change to the current density and the radius of curvature of the magnetic field. The first two appendixes contain practical rules for the free-hand plotting of flux distribution in both air and copper; Appendix C contains an interesting discussion of the conception of vector potential, showing how easily it can be applied to the solution of practical problems.

The three papers in this group should be considered as one complete whole and the reader will find very interesting a comparison between the mathematical plots given in this paper on "Theoretical Considerations" and the experimentally determined plots in the second paper on "Comparison of Calculations and Tests," and the practical uses for these methods in the design of machinery given in "Practical Applications to Salient-Pole Synchronous Machine Design."

In the early days of the design of electrical machinery, magnetic distributions were largely a matter of guesswork, but in these days of more severe competition and closer refinement of design, an accurate knowledge of the magnetic distribution is a necessary fundamental of the greatest importance in determining the best designs.

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all else remaining the same as in the other method.

7. This method of transmission was suggested by General G. O. Squier.

*Both of the Engineering General Department, General Electric Company, Schenectady, N. Y.

Synopsis of paper presented at the Winter Convention of the A. I. E. E., New York, N. Y., February 7-11, 1927. Complete copies upon request.

Abridgment of

The Law of Corona and Dielectric Strength of Air—IV

The Mechanism of Corona Formation and Loss

BY F. W. PEEK[1]

Fellow, A. I. E. E.

Synopsis.—*The mechanisms of corona and corona loss have been studied with the cathode-ray oscillograph. High voltage power of the order of 0.1 watt can be measured with an accuracy of 1 per cent with this instrument. The measurements show that the loss follows the quadratic law above the visual critical voltage.*

On polished wires there is no loss until the visual critical voltage is reached. The loss then starts quite suddenly and takes a finite value on the quadratic curve. On cables and imperfect conductors there is a loss below the visual critical voltage on brushes at local "rough" spots. The loss due to these irregularities can be represented by the probability law. This is quite in accord with former work.

In practise it is important not to mutilate the conductors in stringing. The really important factor in design is the irregularity factor, m_o, for weathered conductors. No line should be operated with a corona loss under fair weather conditions. It is not necessary from the economic standpoint since large diameters can be obtained with special types of conductors.

The visual critical corona voltage can be calculated with great accuracy. As the applied a-c. voltage is increased above the visual critical value, the instantaneous critical voltage becomes lower and lower until finally corona starts at the zero point of the wave. This occurs when the applied voltage is twice the visual critical voltage. At still higher voltage, corona starts below zero or on the falling wave. The effect is as if the instantaneous critical voltage is reduced by an amount approximately equal to the excess of the applied voltage above the visual critical voltage. Thus when the excess is equal to the visual critical voltage the instantaneous voltage is zero. This occurs when the applied voltage is twice the visual critical voltage. The reason for this is clearly shown as well as many other interesting facts.

Artificial corona was readily produced with all of the characteristics of real corona after the mechanism was determined.

The quadratic law seems to be the rational expression for the loss.

Details of measurements are given in the supplemental paper on measurements by Starr and Lloyd, "Methods Used in an Investigation of Corona Loss by Means of the Cathode Ray Oscillograph."

INTRODUCTION

THIS paper records the continuation of an investigation started in 1910, first reported to the Institute in 1911[2] and from time to time thereafter as seemed desirable.

At this time the results of a study with the cathode ray oscillograph are given. This instrument, not available in a very practical form when the investigation was started, has now made it possible to obtain a very good picture of the mechanism of corona formation and loss as well as to measure small losses. The instrument used was of the Western Electric hot cathode type. Probably the first work on corona with the cathode ray oscillograph was done by Prof. H. J. Ryan who has added considerably to our knowledge of this subject.[3]

RESUME AND CONCLUSIONS

The cathode ray oscillograph used in the investigation described in this paper offers a means of studying the mechanism of corona loss as well as a means of measuring accurately small low power factor losses.

This investigation clearly shows the mechanism of corona loss. It was found that the corona loss follows the quadratic law above the visual critical voltage. Below this voltage there is no loss on polished conductors but loss may occur on an imperfect conductor due to local corona at surface irregularities caused by abrasions, dirt, etc. A weathered cable has the characteristic of a dirty wire and may approximate the quadratic down to the disruptive critical voltage. The operating voltage should be below the disruptive critical voltage for the weathered conductor. The losses due to chance irregularities near the critical voltage are closely approximated by the probability law. This quite confirms the results of the former investigations.

The measured visual critical corona voltages check the calculated values very closely.

The cathode ray oscillograms show quite clearly how the corona loss occurs. As the applied voltage is increased above the visual critical voltage, corona starts at a lower and lower instantaneous value of voltage on the a-c. wave. The instantaneous value of starting voltage on the a-c. wave is decreased by an amount approximately equal to the excess of the applied voltage above the visual critical voltage. For instance, when the applied voltage is twice the visual critical voltage, corona starts at the zero point of the voltage wave on each half-cycle. Thus the excess of the applied voltage above e_v is

$$2e_v - e_v = e_v$$

The critical voltage is then decreased by this amount or reduced to

$$e_v - e_v = 0$$

1. Consulting Engineer, General Electric Co., Pittsfield, Mass.

2. Peek, *Law of Corona and Dielectric Strength of Air—I*, TRANSACTIONS, A. I. E. E., 1911, Vol. 30, pp. 1889-1988.

3. Ryan and Henline, *Hysteresis Character of Corona Formation*, TRANSACTIONS, A. I. E. E., 1924, Vol. 33, p. 1118.

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927. Complete copies upon request.

The reason for this is quite evident. After corona starts, a tube of corona surrounds the conductor and is charged through the "corona arcs" up to the maximum of the wave when the arcs go out or corona stops. This corona tube or "space" charge increases quite suddenly to a finite diameter at the start and then more gradually as the maximum of the wave is approached. This charge caused by the excess voltage returns towards the conductor with the falling wave and adds to the charge caused by the applied voltage on the

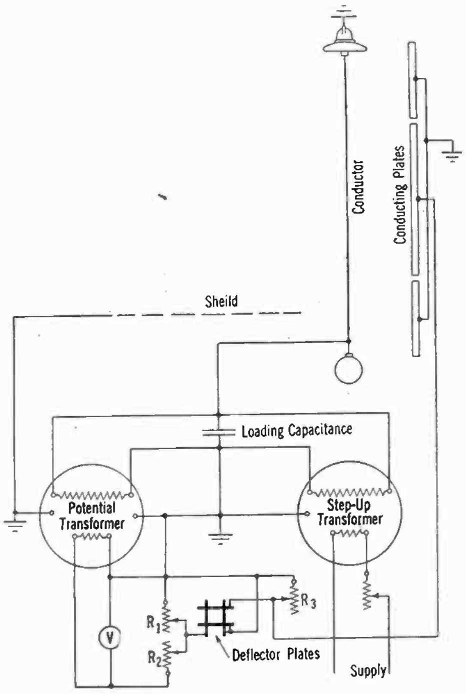

Fig. 1—Arrangement of Vertical Plate and Conductor for a Study of Corona by Means of the Cathode Ray Oscillograph

next half-cycle. When the sum of these charges is sufficient to cause the breakdown gradient, corona starts at an instantaneous voltage less than the visual critical voltage. With the start of corona there is a sudden rush of current. When twice the visual critical voltage is applied, the excess voltage is equal to the critical voltage. The charge due to this excess voltage is then sufficient to cause corona without any additional charge. Corona thus starts on the following half-cycles on the zero of the wave as shown above. If the applied voltage is further increased, corona starts below the zero of the wave or on the falling voltage.

Corona characteristics can be produced artificially by means of condensers. For example, take two condensers and place a gap in series with a resistance across one of them. If voltage is applied and gradually increased, capacity current flows until the gap breaks down. There is a sudden rush of current. The spark, which represents the corona, continues to the maximum of the voltage wave when it stops. This leaves an excess charge on one condenser which adds to the charge caused by the line voltage on the next half-cycle. The gap breaks down at lower and lower instantaneous voltage as the applied voltage is increased and becomes zero when the applied voltage is twice the initial starting voltage as in the case of corona.

It is shown that the loss is caused by the charging of the space condenser through the "resistance" of the corona arc or by the motion of the charge through the field and that the quadratic is the rational form for the loss to take.

The formation of corona current is much faster on the negative than on the positive wave.

The results are of practical as well as theoretical importance. For instance, Fig. 7 shows very decidedly the importance of using care in stringing conductors.

Methods of Tests

The cathode ray oscillograph was connected as shown in Fig. 1. With this arrangement the field across one pair of plates is proportional to the voltage while that across the other pair is proportional to the current. When voltage is applied across a capacity load, an ellipse is described, as shown in Fig. 2, the abscissas being proportional to the instantaneous voltages and the ordinates to the instantaneous current. These figures are recorded photographically. The voltage deflections to the left are positive while those to the right are negative. Positive currents cause deflections above the horizontal axis and negative currents below the axis. If the voltage wave is known, the voltage and current waves can be plotted as shown in Fig. 8. Power is easily obtained by measurements of the instantaneous voltage and current and by simple calculations as follows:

Each figure is divided into an integral number of equal-time sections and the product of the mean

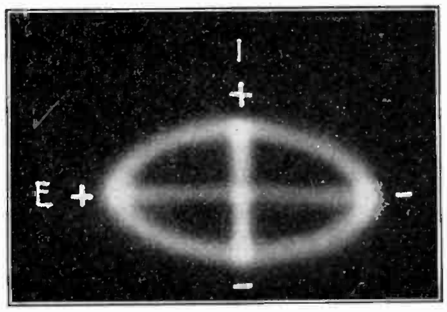

Fig. 2—Cyclogram of Capacity Current Before the Start of Corona

ordinate by the mean abscissa is obtained for each section. The average of all such products is then multiplied by the circuit calibration constants, volts and amperes per unit deflection of the cathode beam. The result is expressed in watts. This is equivalent to transcribing the figures to rectangular coordinates and then integrating the power wave in the usual manner. Power of the order of 0.1 watts can be measured with an accuracy of about 1.0 per cent.

The general arrangement for corona measurements is shown in Fig. 1. The measurements were usually made between a single wire and a plane. Precautions were taken to eliminate the end effect by making the measurements on about 10 ft. of wire in the central part of the plane. Precautions were also taken to guard against stray fields and to prevent phase angle displacement errors.

Since they are very completely covered in the supplemental paper, it is not necessary to go into further details here regarding the measurements.[4]

The assistance of Messrs. W. L. Lloyd, E. C. Starr, T. M. Hotchkiss and other members of the High Voltage Engineering Laboratory Staff in carrying on this investigation, is acknowledged. Mr. Starr's work in making the measurements was especially valuable.

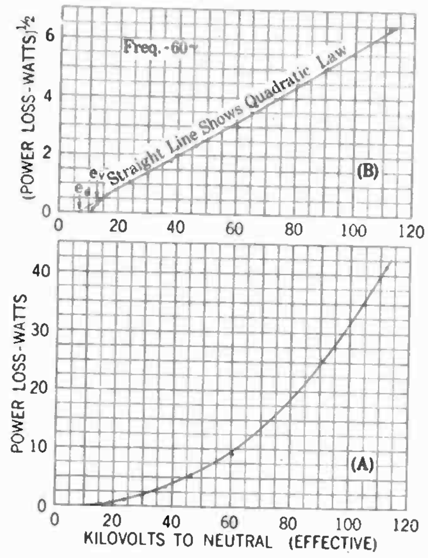

FIG. 3—OBSERVED CORONA LOSS

Measured by means of the cathode ray oscillograph
Conductor: 0.0382 cm. diam. smooth
Spacing: 161 cm. to neutral
Length: 305. cm.

EARLY WORK AND LAWS FOR DETERMINING LOSS AND CRITICAL OR STARTING VOLTAGE

The following brief statement of laws established in the first paper of the series should be of assistance in comparing the earlier work with the present.

The several laws of corona are as follows:

The *visual critical voltage* or the voltage at which corona first starts:

$$e_v = g_v\, r \log_e \frac{s}{r} \text{ kv. to neutral (crest)}$$

$$g_v = 30\,\delta \left(1 + \frac{0.3}{\sqrt{\delta\, r}}\right) \text{ kv. per cm. (crest)}$$

$$\delta = \frac{3.92\, b}{273 + t}$$

Where

r = radius in cm.,
s = spacing in cm.,
t = temp. deg. cent.,
b = barometric pressure cm.,

The power loss is:

$$p = \frac{241}{\delta}(f + 25)\sqrt{r/s}\,(e - e_0)^2\, 10^{-5} \text{ kw. per km. of one conductor}$$

$$e_0 = g_0\, m_0\, r\, \delta \log_e \frac{s}{r} \text{ effective kv. to neutral}$$

$g_0 = 21.1$ m_0 = irregularity factor

For small conductors:

$$e_d = g_0\, \delta \left(1 + \frac{0.30}{\sqrt{\delta r}}\left(\frac{1}{1 + 230\, r^2}\right)\right) r \log_e \frac{s}{r}$$

This has been referred to as the *quadratic law* and states that the loss increases as the square of the excess voltage above the disruptive critical voltage, e_0. The quadratic law obtains when a plot between $\sqrt{p}$ and e gives a straight line. The *disruptive critical voltage*, e_0, is lower than e_v and, in fact, corresponds to a gradient of g_0 = 30 kv. per cm. or the strength of air in a uniform field. In the early work it was stated that with a polished conductor, no loss would be expected below the visual critical voltage e_v. It was further stated that the loss should then start quite suddenly and follow the quadratic law. For rough conductors the loss should be expected below e_v due to the surface irregularities. This should follow because abrasions, dirt and other chance irregularities cause high local stress and thus local corona and loss below e_v. Since local corona is caused by chance conditions, it is difficult to predetermine. It was shown that this loss followed the probability law.

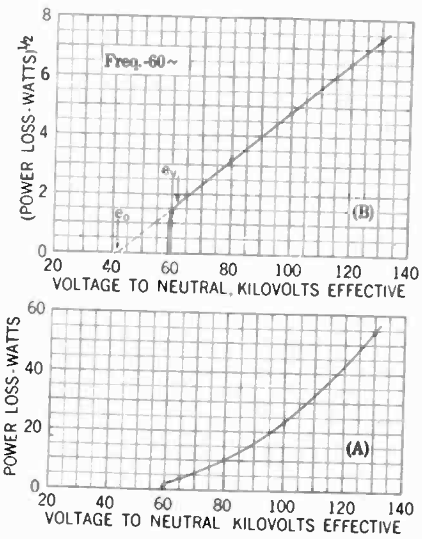

FIG. 4—OBSERVED CORONA LOSS

Measured by means of the cathode ray oscillograph
Conductor: 0.520 cm. diam. polished
Spacing: 161. cm. to neutral
Length: 305. cm.

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4. Lloyd and Starr, *Corona Loss Measurements by Means of the Cathode Ray Oscillograph*, Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927.

Corona Loss Measurements By The Cathode Ray Oscillograph

Power Loss and the Quadratic Law. In Fig. 3A, measurements made by the cathode-ray oscillograph are plotted between loss p, and voltage e, for a small wire. The $\sqrt{p}$ is plotted with e in Fig. 3B where the resulting straight line is the test of the quadratic. The loss starts suddenly at e_v and follows the straight line. The extension of this line cuts the axis at e_0 or e_d. Between e_0 and e_v there is very little loss for this relatively smooth wire. This curve is a check on the

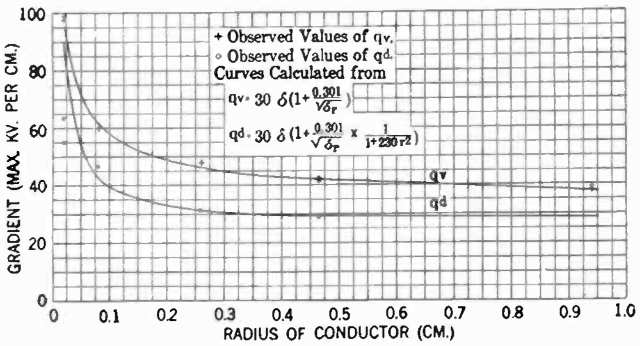


Fig. 5—Critical Disruptive Gradient

quadratic law for voltages up to ten times the starting voltage.

Fig. 4 shows that a larger polished wire also follows the quadratic law above e_v, or that

$$p = k\,(e - e_0)^2.$$

The Disruptive Critical Voltage and Visual Critical Voltage. The disruptive critical voltage e_d or e_0 is due to a gradient of 30 kv. per cm. at the conductor and is the voltage used in the quadratic, for large conductors; e_d is used for small conductors. The gradient g_0 corresponds to the strength of air. Quoting from the first paper, "With perfect conductors loss does not start at the voltage e_0, at which the disruptive gradient is reached at the conductor surface, but only after the disruptive strength of air has been exceeded over an appreciable distance from the conductor, that is, at a higher voltage e_v. With such conductors there would be no loss until e_v were reached. The loss would then suddenly take nearly the definite value calculated for this applied voltage by the equation."[3] With the usual imperfect conductors there is loss below e_v due to tufts of visual corona at local irregularities. Any appreciable corona loss is thus always accompanied by visual corona. For a dirty or mutilated wire, loss occurs at local brushes below the true e_v for the wire. These local losses below or near the critical voltage are difficult to predetermine because they are caused by chance conditions. This is generally not of great practical importance as it is desirable to operate below e_0. The loss on new wires decreases after operation as the irregularities are burned off. The local irregularity loss then becomes insignificant compared to those caused by dew, frost, rain, etc.

Values of g_v and g_d or g_0 determined by the cathode ray oscillograph are the plotted points in Fig. 5. The drawn curves are the calculated values. The check is very good.

Loss Near the Critical Voltage and the Effect of the Condition of the Conductor Surface. In Fig. 6, loss curves are plotted for a rough and for a highly polished wire both directly between p and e and between $\sqrt{p}$ and e. The curve between the $\sqrt{p}$ and e shows that the loss follows the quadratic law. For the polished wire there is no loss until e_v is reached. At that voltage the loss suddenly takes a definite value on the quadratic curve. With the rough wire there is loss below e_v due to local brushes at irregularities. The loss on the rough wire is in excess of the loss on the smooth wire up to about twice e_v. As determined in the early work, this excess loss follows the probability curve

$$p = q\,\epsilon^{-h(e_0 - e)^2}$$

Fig. 7 shows loss curves near e_0 for smooth, rough and mutilated conductors. The excess loss for the mutilated conductor is shown by the dotted line. The ratio between e_0 for the rough and polished wires

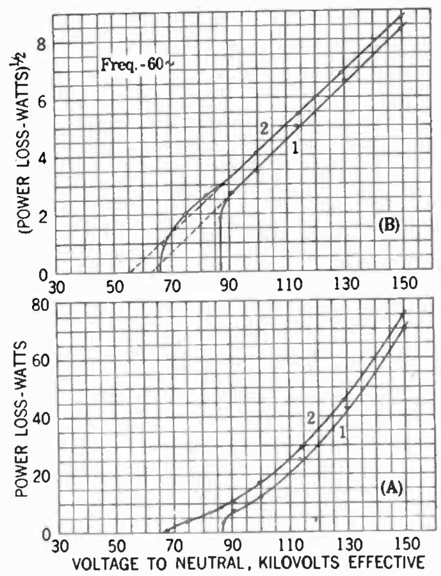


Fig. 6—Observed Corona Loss

Measured by means of the cathode ray oscillograph
Conductor: 0.928 cm. diam. smooth (1)
mutilated (2)
Spacing: 161. cm. to neutral
Length: 305. cm.

gives the irregularity factor m_0. After operation or weathering, the loss at e_0 becomes quite small.

The measurements by the cathode ray oscillograph are thus quite in agreement with laws formulated in the former work as follows:[5]

a. At the visual critical voltage and above, corona loss follows the quadratic law over a wide voltage range, or

$$p = k\,(e - e_0)^2$$

5. (a) Peek, *Law of Corona and Dielectric Strength of Air*, Trans. of the A. I. E. E., Vol. 30, pp. 1889-1988. (b) Peek, "Dielectric Phenomena in High Voltage Engineering," McGraw-Hill.

b. There is no loss below e_v for polished wires.

c. For roughened wires, there is a loss below e_v at spots due to local corona. The critical voltage, e_0, is then decreased by a factor m_0. This irregularity loss follows the probability curve. For the ordinary weathered cable, the loss is generally not far from the quadratic down to e_0.

d. e_0, e_d and e_v check former measurements.

The loss as affected by various factors will be more critically studied later in connection with the cyclograms. In the curves in Figs. 3, 4 and 6, the loss is not reduced to the equivalent of parallel wires. This can be done by a correction factor. The loss is somewhat less than that for parallel wires due to the fact that the ground plate from which current was taken was not of infinite extent. Part of the flux went to this plate and part to the equivalent of an infinite plane. The loss may be corrected so that it corresponds to one of two parallel wires of the given length by multiplying by the proper factor.

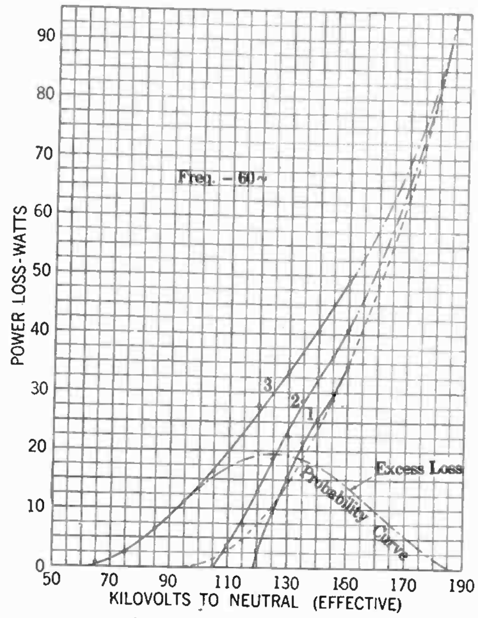


Fig. 7—Observed Corona Loss

Measured by means of the cathode ray oscillograph
Conductor: A. C. S. R. Cable
Aluminum—30 strands, 336,400 cm.
Steel—7 strands
Diam. 0.741 in.
Length: 10.0 ft.
Spacing to neutral: 63.5 in.
1 Clean and smooth
2 Rough
3 Badly mutilated

The Mechanism of Corona or How Corona Forms

The Critical Voltage or Breakdown. The cathode ray oscillograph gives a very good picture of the mechanism of corona formation from instant to instant during the a-c. wave. Some exceedingly interesting facts have been observed. For instance, as the applied voltage is increased above the visual critical voltage, e_v, corona starts at a lower and lower instantaneous voltage on the wave. The instantaneous value of the starting voltage on the a-c. wave actually becomes zero when the applied voltage is approximately $2e$ and finally crosses zero at higher applied voltages.

The visual critical corona voltage or the a-c. voltage at which corona starts when a low voltage is applied and gradually increased, is very sharp and definite and can be determined with accuracy. The formula for calculating this voltage is given above and seems to check well with the present tests. When the voltage is increased above the visual voltage and then reduced, the corona stops at the same voltage at which it started.

Loss occurs when the voltage is above the critical voltage. A study of the instantaneous corona at voltages in excess of the critical voltage is thus important to an understanding of the mechanism of corona loss. Fig. 8 shows a set of cyclograms taken on a wire. The top figure was made just at the start of corona at e_v, and represents capacity current with a slight corona hump at the maximum of the voltage. The ordinates give current, while the abscissas give voltage. Following the X axis to the left, it will be noted that a sudden increase of current or hump starts just before the maximum voltage is reached, and at an instantaneous voltage not far from e_v. At the maximum voltage, the corona hump disappears. The curve is then approximately the capacity ellipse, altered somewhat by the motion of the space charge, until corona starts again on the next half cycle. The polar diagrams have been translated to the usual rectangular co-ordinates at the right. The corona hump is well shown in these figures. It will be noted that the corona starts at a lower and lower instantaneous voltage as the applied

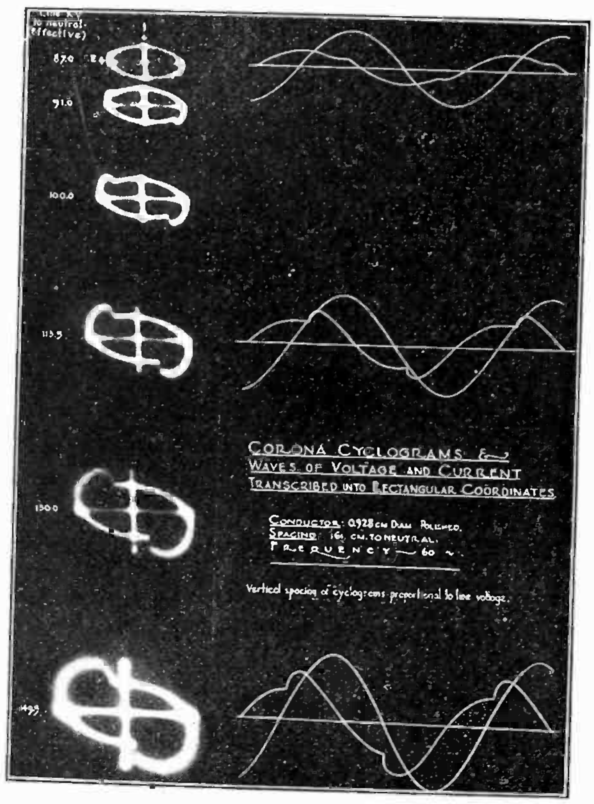


Fig. 8—Variation of Instantaneous Corona Starting Voltage with Applied Voltage

voltage is increased until in the last figure the instantaneous starting voltage on the a-c. wave e_i is almost zero. At a still higher voltage, e_i passes through zero or becomes negative. Referring to Fig. 11A, when the voltage is gradually increased, corona starts at the maximum of the wave when the visual critical voltage e_v is reached. This voltage is very definite. When a higher voltage, e, is applied as in Fig. 11B, corona starts during the first half-

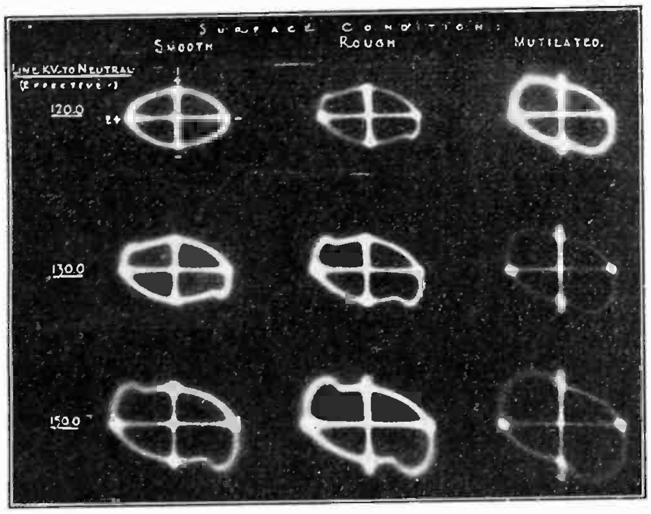


Fig. 10—Comparative Cyclograms Showing the Influence of Conductor Surface Condition upon Corona Discharge Characteristics

Conductor: A. C. S. R. Cable. 0.741 in. diam.
336,400 cm. cross-section area
Spacing: 63.5 in. to neutral

cycle at the instantaneous voltage e_v. The charge on the conductor is then q_v or the flux is ψ_v. e_v is the voltage necessary to produce the flux or the charge required to cause the breakdown gradient g_v. In this particular example, assume that the wire at the start is negative. After corona begins, the positive ions are attracted to it and discharged. The repelled ions become in effect a charged cylinder, of varying diameter, surrounding the conductor. The stress between the conductor and this charged cylinder, or "space charge," now remains more or less constant with increasing voltage or just high enough to maintain the corona charging arcs; see Fig. 15. The stress is limited by the breakdown gradient of the air, g_0. Corona continues to form and to increase the outer cylinder until the maximum voltage is reached or slightly passed, when it stops. At this instant, the stress between the wire and the corona cylinder is just below the breakdown value. With decreasing voltage, the stress between the wire and the space charge decreases and somewhere on the descending wave becomes zero. This leaves for the instant the total flux on the space charge. The conductor and the space charge are then at the same potential. This occurs at $e - e_v$ on the descending wave. If there were no drop in the corona, this condition would occur at the maximum of the wave. With reversal of the voltage, the space charge, in effect, adds to the charge on the conductor. When the sum of these two charges becomes, in effect, equal to q_v, so as to cause a gradient g_v near the conductor surface, breakdown occurs. Then, if the charge due to the voltage is q_i, and that due to the space charge is q_s, breakdown occurs when

$$q_i + q_s = q_v$$

or in terms of flux

$$\psi_i + \psi_s = \psi_v$$

In Fig. 11B, the voltage has been increased above e_v. It is seen that corona starts at the reduced instantaneous voltage e_i on the second or + half-cycle. This is the voltage necessary to produce the flux ψ_i. The effect is as if the charge q_s produced by the excess in the voltage above e_v on the first half-cycle were added directly to the charge on the conductor in the next half-cycle so that corona starts when the sum of these becomes q_v. In other words, corona starts at the instantaneous voltage e_v on the first half-cycle that the voltage is applied. On the next and following half-cycle it starts on the wave at a lower instantaneous voltage, e_i. Fig. 12 shows this graphically.

In Fig. 12A, flux just sufficient to start corona at voltage e_v is shown leaving the conductor. Corona "arcs" are about to form, suddenly increasing the voltage across increased capacity and causing the sudden increase in current shown in Fig. 8. Fig. 12B shows the conditions at the maximum of the voltage wave. The outer cylinder has been charged through the corona "arcs." The stress at the conductor is still sufficient to maintain corona and there is considerable flux from the corona cylinder. The space charge cylinder has been fully charged and the "arcs" die out as the voltage starts to fall. Fig. 12C shows the point on the decreasing wave where all the flux is on the space

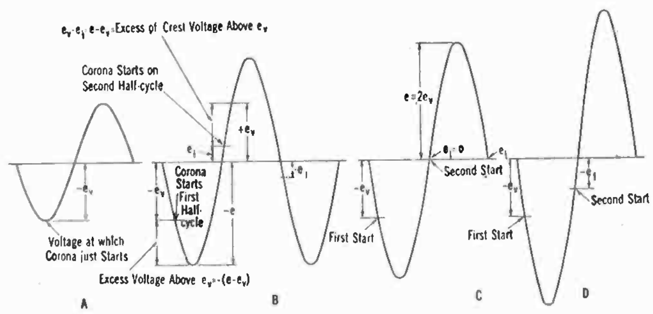


Fig. 11—Mechanism of Corona

charge and there is no voltage between the conductor and the space charge. In Fig. 12D, corona is starting on the second half-cycle at the reduced voltage e_i. The same flux is attached to the conductor as caused by the voltage e_v, in Fig. 12A. The flux is caused partly by e_i and partly by the space charge. It is thus not necessary for e_i to be so great as e_v to cause the breakdown gradient.

The reduction in instantaneous critical voltages is approximately equal to the excess of the applied voltage above e_v. Thus, if e is the applied voltage,

$$e - e_v \cong e_v - e_i$$

or

$$e_i = 2e_v - e.$$

This equation states that the instantaneous starting voltage, e_i, is zero when the applied voltage is $2e_v$, or that when the space charge is in effect q_v, no additional charge is needed to start corona. Instantaneous voltages, e_i, are plotted with applied voltages in Fig. 13. Note that e_i is zero at approximately $2e_v$.

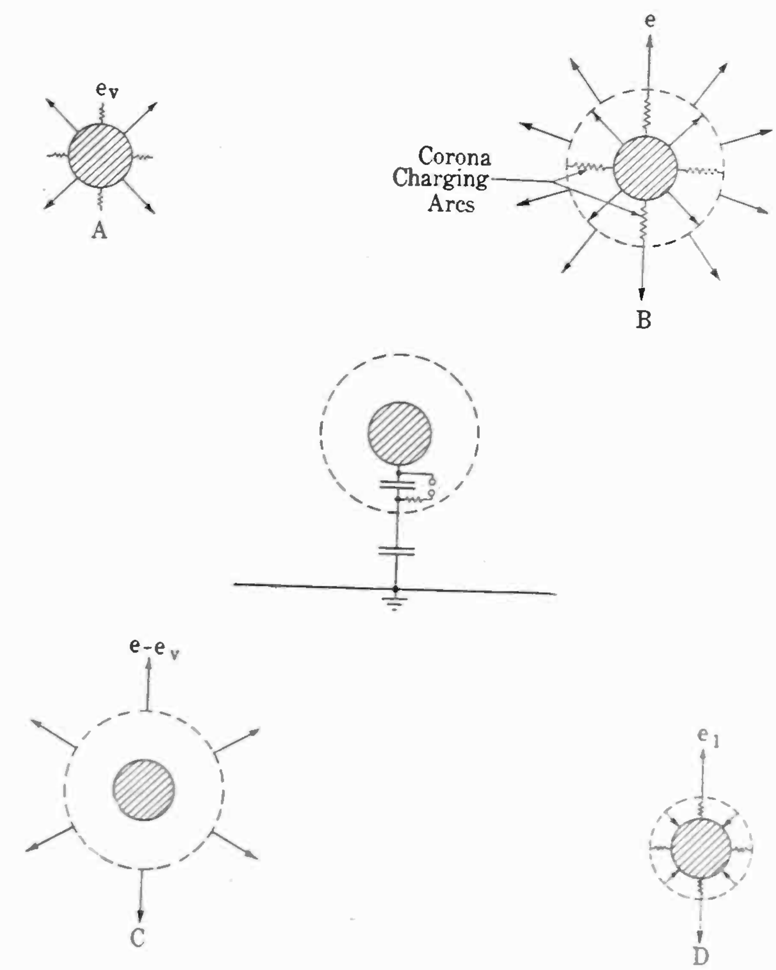


FIG. 12—MECHANISM OF CORONA

A. Just at start of corona. Flux from conductor only

B. Just before corona stops at crest of voltage wave. Flux from conductor and space charge

C. After corona stops. Flux from space charge only

D. Just at second start of corona. Flux from space charge adding to conductor charge

Center figures. Schematic diagram of corona discharge circuit

If the above rule held over a wide range of voltage, it would be found that

$$e + e_i = 2e_v = \text{constant}$$

As a matter of fact, as would be expected, the tests show that $e + e_i$ is not constant, but approximately so, near the critical voltage. Actually, the effect is as if the total space charge were not effective in reducing the critical voltage, but that

$$e_i = e_v - (e - e_v)\, a$$

where a is a leakage factor and is less than unity. Fig. 14 shows this for several different wires. If the total charge were effective, the curves would be parallel to the x axis. At 420 cycles, as would be expected, the leakage is not appreciable.

It is stated above that the stress at the conductor after corona starts does not increase with increasing

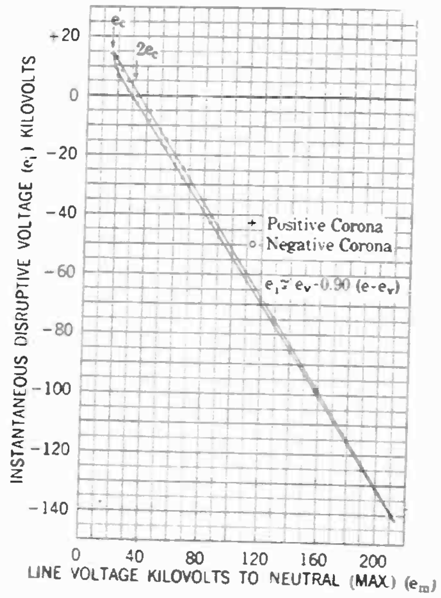


FIG. 13—VARIATION OF INSTANTANEOUS VOLTAGE OF CORONA FORMATION WITH LINE VOLTAGE

Conductor: Solid-smooth surface. 0.015 in. diameter
Spacing to neutral: 63.5 in.

voltage but remains at a value just sufficient to keep the air broken down and to supply the outer cylinder or space charge. This is illustrated by the test curves in Fig. 15. The voltage was measured between the conductor and small wires placed at different points in space. It will be noted that the voltage between these points increases directly with increasing voltage until

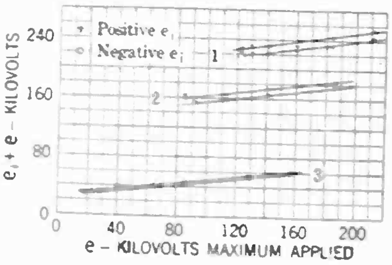


FIG. 14—VARIATION OF $e_i + e$ WITH LINE VOLTAGE

e_i = Instantaneous disruptive corona voltage
e = Maximum line voltage to neutral
Conductor:
1 0.464 cm. radius polished
2 0.260 cm. radius polished
3 0.019 cm. radius smooth
Spacing: 161. cm. to neutral

the critical voltage is reached, after which the voltage remains more or less constant.

Artificial Corona. The mechanism of the corona breakdown can be illustrated with condensers. For the sake of simplicity, take two condensers as in Fig. 16. Shunt one of these with a gap set to spark at voltage e_1 and of such characteristics that it never short-circuits c_1. This gap thus has a valve action sparking when a voltage e_1 is impressed across it but not short-circuiting

c_1. On the first half-cycle, the spark, which represents the corona, starts at the instantaneous line voltage e_v, because e_v is the total applied voltage that causes the breakdown voltage e_1 on c_1. At that instant the voltage across c_2 is $e_v - e_1$. With increasing line voltage, the voltage across c_1 does not rise above e_1 because of the arc. The excess voltage is placed across c_2. When the maximum of the wave is reached, the current

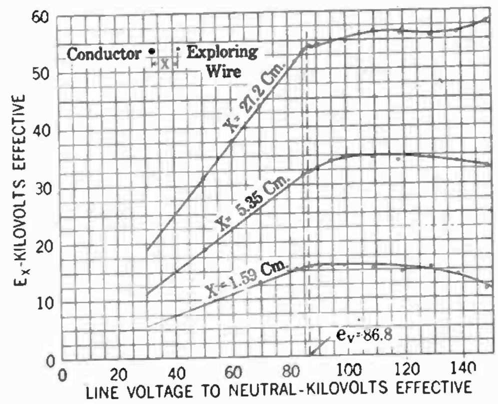


FIG. 15—EXPLORATION OF STATIC FIELD SURROUNDING A CONDUCTOR

X = Distance from conductor center to equipotential surface
E_x = Voltage across space X
Conductor: solid copper, polished
0.927 cm. diameter
Spacing: 161. cm. to neutral
Critical disruptive corona voltage—86.8 kv.

stops and the arc goes out. At a voltage $e - e_v$ on the falling quarter of the wave, the total voltage is on c_2. Finally, on the + half of the wave, the voltage across the gap again becomes e_1 and the spark again starts. This occurs at the instantaneous line voltage e_i. This is lower than the instantaneous voltage e_v at which corona started on the first half-wave, by the amount that e exceeded e_v because an excess charge, $(e - e_v)\ c$, on c_1, adds to the charge due to the line voltage, or

$$e - e_v = e_v - e_i$$
$$e_i = 2e_v - e$$

This is the relation arrived at for corona on wires and as in the case of corona, the spark starts at zero instantaneous line voltage when the applied voltage is twice the critical voltage. The above holds whatever A similar voltage relation holds if the gap is permitted to short-circuit the condenser except that the gap must then be set at double voltage. The voltage relations are followed out for several half-cycles in Fig. 16. The arrows on the condensers show the relation of the fluxes at different parts of the wave. In one instance it will be noted that all of the flux is attached to the "space charge" or condenser c_2.

Compare Fig. 16 with Fig. 12, where the same relations are shown for actual corona and space charge.

The cyclograms in Fig. 18 show how closely artificial corona agrees with actual corona.

The Power Loss. The mechanism has so far been described up to the point where the charge of the ionized the relation between the capacities of the condensers, or whether one gap is used or several gaps are used to breakdown successively. The actual corona loss relation would be more nearly approached with a successive breakdown of gaps with increasing voltage. space of the first half-cycle in effect adds to the charge on the conductor of the next half-cycle and breakdown occurs when the sum of these two charges is in effect equal to q_v, or causes a stress g_v. In this particular case, the start was made with the wire (−). The returning charge was then also (−). Following the new break, this was cancelled by a (+) charge while a (+) charge was repelled from the conductor. The space charge cylinder moves out with increasing voltage and is charged through the corona arcs until the wave reaches maximum. The arcs then die out or corona stops. The sudden increase of current at the critical voltage is caused by a sudden increase of voltage across the increased capacity. Part of the energy in the "space charge" field is returned to the circuit and part of the energy is not returned or is returned at the wrong part of the wave and is lost. When the conductors are far apart, the main part of the loss occurs in the space between the conductor and corona cylinder. Where the conductors are close together, or the voltage is approaching the spark-over voltage, a conduction loss is also caused by ions migrating to the opposite conductor. The measurements show that over a very wide range of conditions the loss follows the quadratic law

$$p = k_1\ (e - e_0)^2$$

An examination of the mechanism makes this appear the rational form for the loss to take. This seems so

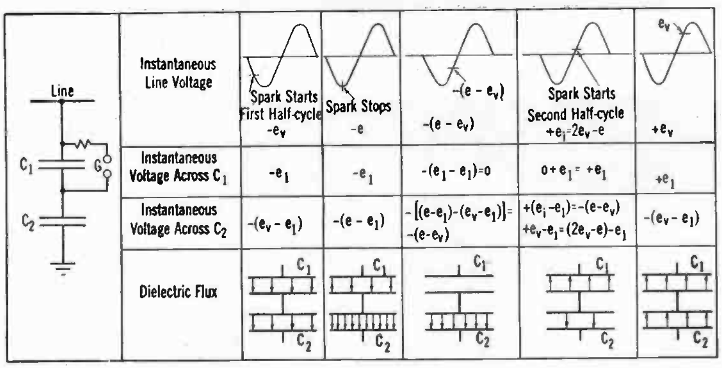


FIG. 16—OPERATION OF SINGLE-GAP, FIXED-CAPACITANCE ARTIFICIAL CORONA CIRCUIT

for the following reasons: The space charge is proportional to $(e - e_0)\ C$. Energy is required to move this charge through the field or through the voltage from the conductor to the corona cylinder. The voltage between the conductor and the space charge or corona cylinder is proportional to $(e - e_0)$ and, in fact, appears to equal $(e - e_0)$ for the higher frequencies and very large spacings. The energy may be considered as being lost in the resistance of the corona arcs charging and discharging the corona cylinder. The loss is thus

$$w = (e - e_0)\ (e - e_0)\ k\ C = (e - e_0)^2\ k\ C$$

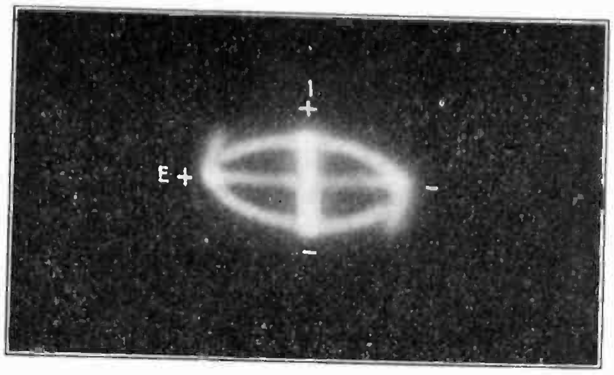
or the power

$$p = 4\ f\ C\ k\ (e - e_0)^2$$

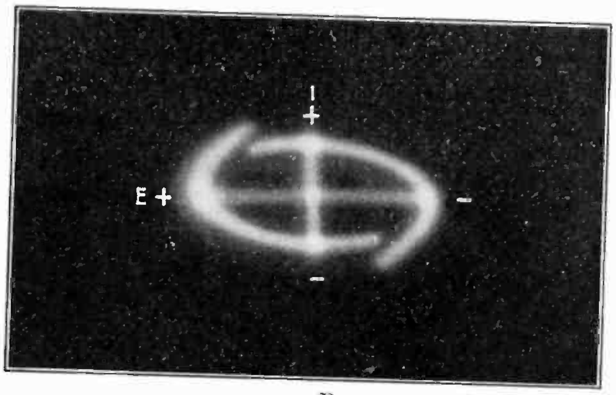
The above relation checks the measured values for large spacings at 60 cycles and for all spacings at 420 cycles. When the frequency is low or when the spacing is small, ions must pass from conductor to conductor. This is equivalent to a leakage loss or loss in a resistance intermittently placed from conductor to conductor. Then

$$p = k_2 (f + a) C (e - e_0)^2$$

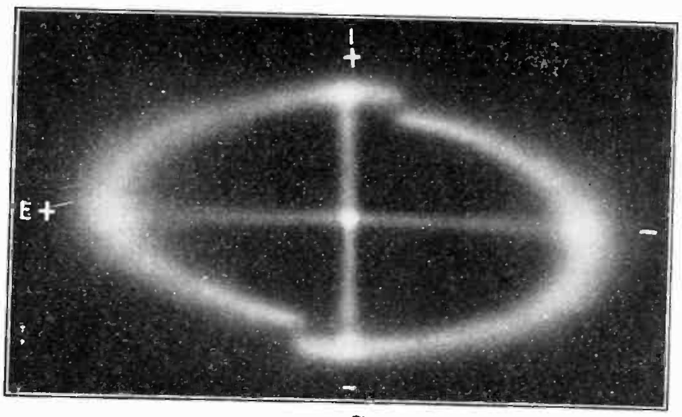
wherein the factors a and k are an integral part of the



A



B



C

Fig. 18—Artificial Corona

A—Just above critical voltage
B—Considerably above critical voltage
C—Over twice critical voltage—corona starting "below zero"

equation and were originally determined empirically in the quadratic law. The part of the energy in the space charge that is returned to the circuit at the proper part of the wave is not lost but gives the extra capacity effect of corona.

There is no loss at e_0 because breakdown does not take place until the voltage e_v is reached. There is then a sudden break over a finite distance from the conductor and the loss falls on the quadratic curve with e_0 as the disruptive critical voltage. The stress between the conductor and the corona cylinder is not reduced to zero when corona starts but has a value approximately equal to g_0 or g_d at the conductor and decreases outward to the corona cylinder along approximately the same curve that obtained just before corona started. Beyond the corona cylinder, the average stress must be higher or the curve flatter to maintain the voltage proportional to e_0 across the portion that is not ionized.

It might be expected at first glance that the disruptive critical voltage should be e_v rather than e_0, since loss does not start on polished conductors until e_v is reached. A more critical examination, however, shows that following the initial break controlled by g_v, the strength of air becomes g_0. Thus, although g_v controls the start of the loss, after the initial break occurs and corona extends out, the controlling gradient is g_0. This follows up to the maximum of the voltage wave when corona stops. g_v is required to cause the next start, etc.

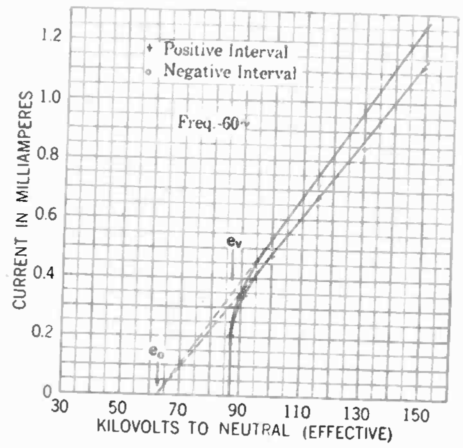


Fig. 19—Effective Corona Current During Disruptive Interval

Conductor: 0.927 cm. diameter, polished
Spacing to neutral: 161. cm.
Length: 305. cm.

It is interesting that when the applied voltage is zero, all of the energy is on the space charge and is

$$(e - e_v)^2 \frac{C\,C_2}{2\,C_1}$$

For a polished wire the instantaneous corona start is extremely rapid on the negative half of the wave, while on the positive half it is more gradual. The start on the negative half is so rapid that oscillations are readily produced. The effect of the conductor surface is shown very well in Fig. 10. A cable acts very much like a dirty wire.

An examination of the power curves shows a difference for (−) and (+) corona. There is not, however, any great difference in the actual loss on the different half-cycles.

Figs. 13 and 14 show a slight difference in the instantaneous starting voltages.

The corona at 420 cycles follows the quadratic law.

Heating of Windings Determined from Tests of Short Duration

BY JOHN BASTA[1] AND FRANK FABINGER[1]

Synopsis.—This paper describes the calculation of the "hot spot" temperature rise in an electric machine from data obtained by a load test of short duration. The chief difference between this method and those previously used is that a simple exponential curve for the heating has usually been assumed, while the present method endeavors to follow more closely the actual conditions.

Introduction

THE heating of electrical machines and apparatus under operating conditions restricts the output to certain limits, and for this reason, considerable study has been given to this subject. Notwithstanding the fact that it has been demonstrated several times recently that the heating curve of a normal electrical machine does not follow a simple exponential law, it is found that in electrotechnical practise, the old methods are still being used although they do not give results that check the actual measurements for the complete curves.

As a proof of this variation, the rules for making such a calculation from the "Rules and Standards of the Czechoslovakian Electrotechnical Association 1923," p. 425, will be followed in determining the hot-spot temperature rise of a current transformer constructed by the Ceskomoravska-Kolben Company, Prague, Czechoslovakia.

The auxiliary line to the left of vertical axis of Fig. 1 is obtained by plotting the slope $\frac{d\,\theta}{d\,t}$ of the temperature-rise curve against temperature rise. The auxiliary

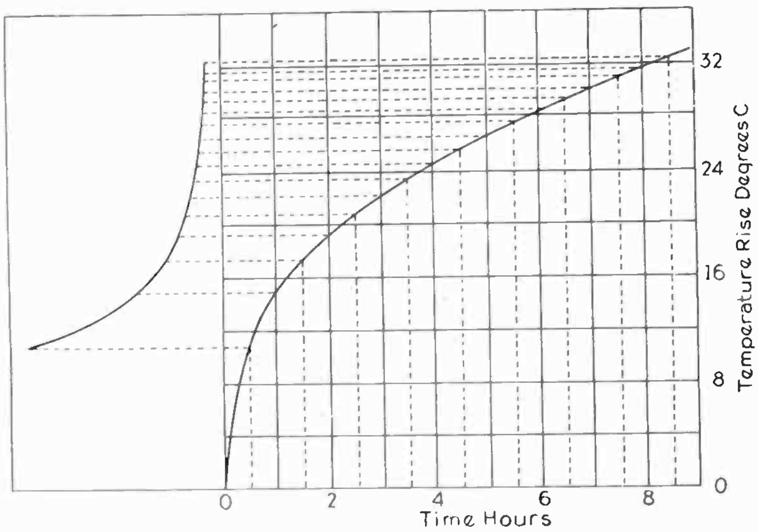


Fig. 1

line of the curve should be a straight line if the curve follows the simple exponential formula

$$\theta = \theta_1 (1 - \epsilon^{-kt})$$

This figure is derived by the application of the rule and is a proof that the final temperature rise cannot be accurately determined by applying the older methods because the auxiliary line differs substantially from a straight line. Likewise, the failure of the rule to give

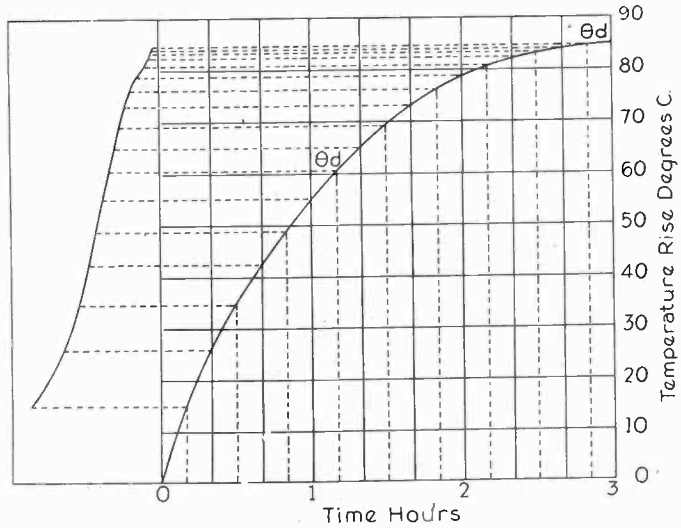


Fig. 2

correct results for rotating electric machines is shown in Fig. 2, which is the heating curve of the stator winding of an induction motor, built by the same company. Again, the auxiliary line cannot be used because of its deviation from a straight line.

Derivation of Formula for Temperature Rise of an Induction Motor

A formula for the hot-spot temperature rise of this induction motor will now be derived. Fig. 3 shows one coil of the stator. The parts of the coil imbedded in the slots transmit the heat to the surrounding iron which is however, also, heated by its own losses. Therefore the slot portions of the coils are not cooled as effectually as the ends, which are more favorably situated in the cooling air. Since the ends of the coils are usually cooler than the parts imbedded in the slots, there will be a flow of heat toward the ends. The distribution of the temperature along the coil, assuming a symmetrical ventilation, will be represented by a curve, the maximum point being located inside the machine and the minimum in the ends of the coils. (See Fig. 4, a-b.) The problem may be simplified by the assumption that the temperatures of the slot and end sections are uniform, being θ_d for the slot and θ_h in the end sections.

1. Both of the Ceskomoravska-Kolben Co., Prague, Czechoslovakia.

(Fig. 4c). Then the flow of heat is due to the difference in temperatures. Let Q be the quantity of heat in watts passing in one second between two equal cross-sections of S sq. cm. located "a" centimeters apart, and with a heat conductivity λ.
Then

$$Q = \frac{\lambda S}{a} (\theta_d - \theta_h)$$

The heat from the slot section flows in both directions to the ends of the coils and the cross-section S is therefore equal to twice the area of the copper in all the stator slots. The distance flow of the heat must now be

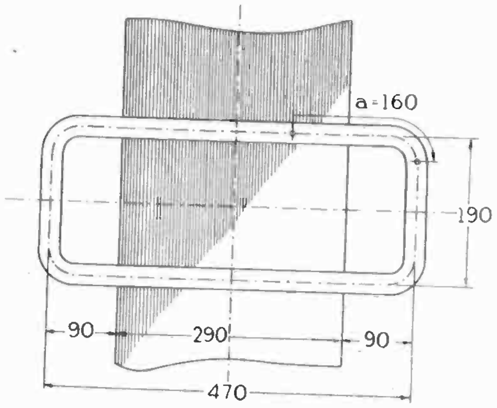


FIG. 3

determined. The cross-sections, through which there is no heat flow, are located approximately in the middle of the imbedded part in the slots and in the center of the end portions or heads of the coils. These cross-sections are indicated in Fig. 4c by interrupted lines, and the distance a between them is also shown in this figure. The outline drawing of the coil Fig. 3 also shows the points between which the heat flow takes place.

The further derivation of the equations for heat transfer requires the introduction of the following notation:

θ_0 = Temperature of the surrounding medium.
θ_m = Temperature rise of the iron.
θ_h = Temperature rise of the heads of the windings.
θ_d = Temperature rise of the slot portion of the windings.
α_m = D'ssipation constant of iron.
α_h = Dissipation constant of heads of the windings.
α_d = Dissipation constant of the slot portion of the windings.
C_m = Thermal capacity of the iron.
C_h = Thermal capacity of the heads of the windings.
C_d = Thermal capacity of the slot portion of the windings.
S = Double total area of copper in all stator slots.
λ = Thermal conductivity of copper in watts.
a = Distance between the characteristic sections of the windings.
Q_m = Iron loss in watts.
Q_h = Copper loss in heads of winding in watts.
Q_d = Copper loss in slot portion of winding in watts.

The equations for the dynamic balance of heat for all three parts of the stator will now be derived:

$$Q_d = C_d \frac{d\,\theta_d}{d\,t} + \alpha_d (\theta_d - \theta_m) + \frac{\lambda S}{a} (\theta_d - \theta_h) \quad (1)$$

$$Q_h + \frac{\lambda S}{a} (\theta_d - \theta_h) = C_h \frac{d\,\theta_h}{d\,t} + \alpha_h \theta_h \quad (2)$$

$$Q_m + \alpha_d (\theta_d - \theta_m) = C_m \frac{d\,\theta_m}{d\,t} + \alpha_m \theta_m \quad (3)$$

These simultaneous differential equations lead to three relations for θ_d, θ_h and θ_m as functions of time t. The integrals of these relations give heating curves which differ substantially from ideal exponential curves. The determination in advance of the final temperature of the individual parts requires two points on each heating curve. One of these points marks the beginning and is common to all curves; the second set of points may be obtained from test continuing until reasonable temperature rises are attained, for instance, for 40 minutes. The test can then be stopped, as it will be possible to draw tangents to the curves, the slope of which will express the relations $\frac{d\,\theta}{d\,t}$.

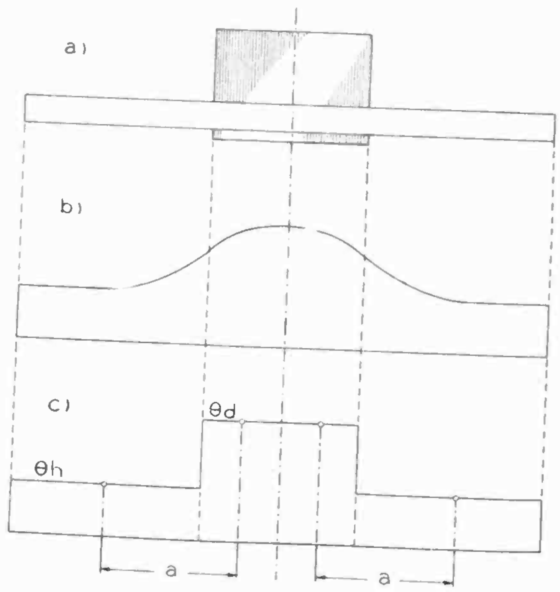


FIG. 4

At the time $t = \infty$ each part of the stator reaches its highest temperature and the derivatives become zero and are eliminated from the equations.

The solutions of the equations then give the highest temperature rise for the three parts:

$$\theta_h = \frac{Q_h + \frac{\lambda S}{a} \theta_d}{\alpha_h + \frac{\lambda S}{a}} \quad (4a)$$

$$\theta_m = \frac{Q_m + \alpha_d \theta_d}{\alpha_m + \alpha_d} \quad (4b)$$

$$\theta_d = \frac{Q_d\,(\alpha_m + \alpha_d)\left(\alpha_h + \frac{\lambda\,S}{a}\right) + Q_h\,\frac{\lambda\,S}{a}(\alpha_m + \alpha_d) + Q_m\,\alpha_d\left(\alpha_h + \frac{\lambda\,S}{a}\right)}{(\alpha_m + \alpha_d)\,\frac{\lambda\,S}{a}\,\alpha_h + \alpha_d\,\alpha_m\left(\alpha_h + \frac{\lambda\,S}{a}\right)} \quad \textbf{(4c)}$$

It is obvious that the calculation of the hottest spot temperature rise is now reduced to the determination of the values of the α constants. For this purpose the starting parts of the heat'ng curves may be used. (See Fig. 5).

The evaluation of equations **1**, **2** and **3** for $t = o$ results in values for the thermal capacities of the three parts of the stator.

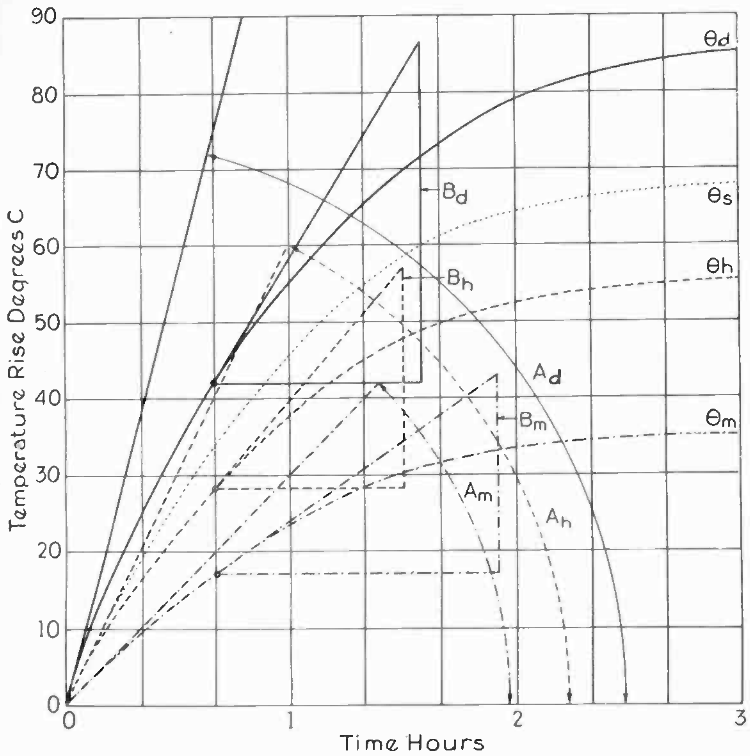


FIG. 5

$$C_d = \frac{Q_d}{A_d} \quad (5)$$

$$C_h = \frac{Q_h}{A_h} \quad (6)$$

$$C_m = \frac{Q_m}{A_m} \quad (7)$$

where

A_d = slope of the tangent to the heating curve for the windings in the slot at the starting point.

A_m = corresponding value for the heating curve of the iron.

A_h = corresponding value for the heating curve for the heads of end portions of the windings.

Knowing these values, it is now possible to determine the values of the dissipation constants α_d, α_m and α_h from the short time heating test data. In the time t_1 the temperature rises θ_{d1} θ_{h1} and θ_{m1}, have been attained. Using a mirror, the tangents are drawn to the heating curves for $t = t_1$ and the slopes of these tangents B_d B_h and B_m are evaluated.

The equations **1**, **2** and **3** for $t = t_1$ will then be:

$$Q_d = C_d\,B_d + \alpha_d\,(\theta_{d1} - \theta_{m1}) + \frac{\lambda\,S}{a}(\theta_{d1} - \theta_{h1}) \quad \textbf{(8)}$$

$$Q_h + \frac{\lambda\,S}{a}(\theta_{d1} - \theta_{h1}) = C_h\,B_h + \alpha_h\,\theta_{h1} \quad \textbf{(9)}$$

$$Q_m + \alpha_d\,(\theta_{d1} - \theta_{m1}) = C_m\,B_m + \alpha_m\,\theta_{m1} \quad \textbf{(10)}$$

The solution of these equations determines the values of α.

The process just explained requires the measurement of the temperature rises of the iron, of the ends of the windings, and of the slot portions of the windings during a test at a certain load. The temperatures of the iron and of the ends of the windings are obtained by thermometers or by temperature detectors suitably placed. There is an error introduced if the readings of thermometers on the ends are taken directly, since the bulb touches only the outside of the insulation. The corrections for the actual temperature of the windings are investigated in Appendix I.

The temperatures of the windings in the slots can be directly measured only by temperature detectors located between the upper and lower half coils. When the machines do not have temperature detectors in the slots, it is possible to determine the temperature of the copper in the slot θ_d from the temperature θ_s ascertained from measured resistance and from the temperature of the ends θ_h. The derivation of θ_d from the measured values of θ_h and θ_s is outlined in the Appendix II.

The formula

$$l_h\,\theta_h + l_d\,\theta_d = l\,\theta_s \quad \textbf{(11)}$$

derived in Appendix II demonstrates that the temperature rise ascertained from resistance measurements is a mean value of the temperature rise of the heads of the windings, and that of the windings in the slots.

EXAMPLE OF CALCULATIONS AND VERIFICATION BY TEST RESULTS

Fig. 5 shows the heating curves of a three-phase induction motor, designed for a continuous rating of 80 amperes at 500 volts. The motor is of open construction and symmetrically ventilated. The heating test, however, was made with a current of 200 amperes at 275 volts, and the temperature rises are higher than those corresponding to the normal rating.

The losses during this test were:

In iron Q_m = 270 watts

In stator copper = $1500\left(\frac{200}{80}\right)^2$ = 9400 watts

The copper losses are distributed between the end and slot portions of the stator windings in the ratio to their lengths:

$$Q_d = 9700 \times \frac{58}{132} = 4130 \text{ watts}$$

$$Q_h = 9700 \times \frac{74}{132} = 5270 \text{ watts}$$

Length of coil in the slot l_d = 58 cm.
Length of coil in the head l_h = 74 cm.
Length of total coil = 132 cm.

These values are obtained from Fig. 3, on which dimensions are given in millimeters.

The curve for θ_d in Fig. 5 is obtained from the curves for θ_h and θ_s by the use of the following formula derived from (11)

$$\theta_d = \frac{l}{l_d}\theta_s - \frac{l_h}{l_d}\theta_h \qquad (12)$$

The beginnings of the heating curves during the first 40 minutes will now be used in an attempt to check the final temperatures. The slopes of the curves at zero time on Fig. 5 are:

$$A_d = 3.75$$
$$A_h = 2.0$$
$$A_m = 1.0$$

But 40 minutes later the following temperature rises were attained:

$$\theta_{d1} = 42 \text{ deg. cent.}$$
$$\theta_{h1} = 28 \text{ deg. cent.}$$
$$\theta_{m1} = 17.4 \text{ deg. cent.}$$

The slopes of the tangents at this time are

$$B_d = 1.6$$
$$B_h = 1.13$$
$$B_m = 0.69$$

The value of $\frac{\lambda S}{a}$ is now required.

The thermal conductivity λ of copper is approximately 3.4.

The double cross-section of copper in all the stator slots is

$$S = 2 \times 72 \times 6.33 \times 2 \times 16$$
$$= 29200 \text{ sq. mm.}$$
$$= 292 \text{ sq. cm.}$$
$$a = 16 \text{ cm. from Fig. 3.}$$

$$\frac{\lambda S}{a} = \frac{3.4 \times 292}{16}$$

$$= 62$$

Thus, all the values necessary for the evaluation have been determined.

Substituting in equations **5, 6, 7**

$$C_d = \frac{4130}{3.75} = 1100$$

$$C_h = \frac{5270}{2} = 2635$$

$$C_m = \frac{270}{1} = 270$$

Further substitution in **8**, **9**, **10** gives the following results:

$$4130 = 1100 \times 1.6 + \alpha_d (42 - 17.4) + 62 (42 - 28)$$
$$\alpha_d = 61$$
$$5270 + 62 (42 - 28) = 2635 \times 1.13 + \alpha_h \times 28$$
$$\alpha_h = 113$$
$$270 + 61 (42 - 17.4) = 270 \times 0.69 + \alpha_m \times 17.4$$
$$\alpha_m = 91$$

By the aid of these values, equation (**4c**) may be evaluated

$$\theta_d = \frac{4130 (91 + 61)(113 + 62) + 5270 \times 62 (91 + 61) + 270 \times 61 (113 + 62)}{(91 + 61) \times 62 \times 113 + 61 \times 91 \times (113 + 62)}$$

$$= 80 \text{ deg. cent.}$$

By using θ_d = 80 deg. in (**4a**) and (**4b**):

$$\theta_h = \frac{5270 + 62 \times 80}{113 + 62}$$

$$= 58.5 \text{ deg. cent.}$$

$$\theta_m = \frac{270 + 61 \times 80}{91 + 61}$$

$$= 34 \text{ deg. cent.}$$

The following tabulation compares the calculated final temperature rises with the values ascertained by test measurements.

Temperature rise	Measured deg. cent.	Calculated deg. cent.	Difference	
			Deg. cent.	Per cent
θ_d	85	80	−5	−5.9
θ_h	56	58	+2	+3.5
θ_m	35	34	−1	−2.86

Appendix I

The thermal potential θ in the insulation can be expressed:

$$\theta = 760\, q\, s$$

where

q = losses in coil in watts per sq. cm. of coil surface.

and

s = thickness of coil insulation in centimeters.

The machine has 90 kg. of copper in the stator, which is equal to about 10,000 cu. cm. The copper loss is approximately 1500 watts, and the loss per cu. cm. is 0.15 watts.

The slot dimensions are 1.2 cm. wide and 4.6 cm. deep, giving a circumference:

$$O = 2 (1.2 + 4.6)$$
$$= 11.6 \text{ cm.}$$

In a length of coil at the head of the machine of 1 cm., the radiating surface for a coil is 11.6 sq. cm. The cross-section of the copper is 2 sq. cm. and the quantity per cm. length is therefore 2 cu. cm. The heat generated in this amount of copper is

$$2 \times 0.15 = 0.3 \text{ watts}$$

The loss per unit of radiating surface is:

$$q = \frac{0.3}{11.6} = 0.0259 \text{ watts per square cm.}$$

The thickness of the insulation is $s = 0.1$ cm., and the thermal potential, assuming all the heat to pass through the insulation, is

$$\theta = 760 \times 0.0259 \times 0.1 = 1.97 \text{ deg.}$$

This represents an error of about 4 per cent if the mean temperature rise of the heads is 50 deg. cent.

Appendix II Derivation of Formula 11 For Temperatures by Resistance

The expression for the resistance of the entire coil can be determined by adding the resistance of the parts of the coil which are exposed to the air and the resistance of the imbedded portions; or the resistance of the entire coil may be used. In either case the influence of the temperatures of the various parts must be taken into account.

If the accuracy of a first approximation is allowable, the expression derived is:

$$\delta = \frac{\delta_0}{l + \alpha\,\theta}$$

where δ_0 = the specific conductivity of copper at the original temperature.

α = temperature coefficient per deg. cent

θ = temperature rise-deg. cent

The coil dimensions may be represented as follows:

$\frac{S}{2}$ = cross-section of copper

l_d = length of imbedded part in the iron.

l_h = length of heads of coils

Let R_h = mean resistance of winding at heads

and R_d = mean resistance of winding imbedded in iron.

Then

$$R_h = \frac{l + \alpha\,\theta_h}{\delta_0}\,\frac{2\,l_h}{S}$$

and

$$R_d = \frac{l + \alpha\,\theta_d}{\delta_0}\,\frac{2\,l_d}{S}$$

$$R = R_h + R_d$$

$$= \frac{2}{\delta_0\,S}\,[(l + \alpha\,\theta_h)\,l_h + (l + \alpha\,\theta_d)\,l_d]$$

The measured resistance of the entire coil gives a mean temperature rise θ_s and a second expression for R may be derived from it, namely:

$$R = \frac{2}{\delta_0\,S}\,(l + \alpha\,\theta_s)\,l$$

Equating the two values of R gives:

$$\frac{2}{\delta_0 S}\,[(l + \alpha\,\theta_h)\,l_h + (l + \alpha\,\theta_d)\,l_d] = \frac{2}{\delta_0 S}\,(l + \alpha\,\theta_s)\,l$$

Simplifying:

$$l_h\,\theta_h + l_d\,\theta_d = l\,\theta_s \qquad \textbf{(11)}$$

Bibliography

Dr. F. Fabinger, "Prispĕvek k Theorii Oteplování Electrickych Stroju," E. O. 1923.

V. Karapetoff, *Parameters of Heating Curves of Electrical Machinery*, A. I. E. E. Journal, January 1926, pp. 40-42.

A. E. Kennelly, *Can the Thermal Capacity Be Made a Simple and Practical Element of Rating*, A. I. E. E. Journal, May 1926, pp. 438-445.

LARGE POWER WORKS UNDER CONSTRUCTION IN SWITZERLAND

Great developments are going on in the realm of the Grimsel, leading from Meiringen to Gletsch (Rhone Glacier). Here, for a number of years, engineers and workmen have been busily engaged in the construction of the Oberhasli Power Works, more generally known as the Grimsel Works.

For this project the River Aare, discharged by the Unter and the Oberaar Glaciers, is utilized to Innertkirchen, near Meiringen, in three stages. The total fall amounts to some 4175 ft. Two reservoir lakes at Gelmar and on the Grimsel will have an effective capacity of 113,000,000 m.^{3} The drainage area of the lakes comprises 111 km.^{2}

The Aare is dammed at the Grimsel by two concrete walls, 100 m. and 30 m. high. The surface of the Grimsel Lake amounts roughly to 2.5 km.^{2}, the effective capacity to 100,000,000 m.^{3} The Gelmar Lake is raised 30 m. by damming, and a lake of 0.6-km.^{2} surface and 13,000,000 m.^{3} effective capacity is formed. The connecting tunnel between the two lakes is 5.25 km. long, and its diameter 2 m. The conduit from Gelmar Lake to the power station is formed by an armoured pressure shaft of two 2.2 m. diameter. The Handeck Power Station will contain four vertical-shaft units, each of 25,000 h. p. The current is transmitted under a pressure of 50,000 volts by means of cables into the valley. The transformation to 150,000 volts is effected in an outdoor substation at Innertkirchen.

There are three power stations, located at Handeck, Boden, and Innertkirchen, respectively. The Handeck Power Station will generate a constant yearly output of 223,000,000 kw-hr.; after completion of the two lower stages, the aggregate constant yearly output measured at Innertkirchen under 150,000 volts can be raised to 538,000,000 kw-hr. It is also possible to provide further storage ponds and utilize further streams in the Oberhasli region.

The project was launched by the Bernische Kraftwerken (Bernese Power Works).

The Electric Arc and its Function in the New Welding Processes

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Member, A. I. E. E.

Synopsis.—*The subject of this paper is a phenomenon of great interest and very great complexity. The electric arc is a tool of extreme power and flexibility. The electric arc can be used to melt the most refractory substances, cut the armor plates of battleships or weld together the ends of wires no thicker than a human hair. It is a wonderful tool that makes or breaks almost anything. It may unite the most indifferent elements such as nitrogen and oxygen, or break the molecule into its constituent atoms.*

In this paper we shall discuss only one type of application of the electric arc; namely, the application of the arc to the welding of metals, but even in these limits the field is very wide.

The electric arc was discovered by H. Davy who in 1810 was experimenting with the sparking between two horizontally disposed carbon pencils. The density of the current was such that on short circuit the tips of the carbon pencils were heated to incandescence. When the electrodes were separated the electric current continued to flow across the air-gap between the carbon pencils. The air-gap was bridged by some sort of an extremely bright band which under action of the accending currents of hot air was bent upwards and formed a bow or an "arc." This is the origin of the term, the "electric arc."

For many years the electric arc was used only as a source of light. It was only years later that the electric arc was applied for the purpose of melting and welding metals together. In 1881 de Meritens for the first time used a small carbon arc for melting and welding the lead terminals of storage batteries. The more extensive application of the carbon arc was done by Bernardos.

This process was modified by Dr. Zerener of Berlin, Germany, who shortly prior to 1890 invented a process of welding with a flaming arc. In this process two carbon electrodes are disposed to form a "V". The arc is drawn between the two electrodes and caused to impinge upon the metal to be welded by being forced down by a powerful electromagnet. This arrangement caused the arc to act in a similar manner to the flame of an oxyacetylene flame. The energy developed in this arc is only partly transmitted into the weld and the efficiency of the method is very low.

The third type arc welding known now as a metallic arc process was discovered about 1890 by H. Slawianoff.

This engineer conceived the idea of producing steel ingots by an electrical casting process. Metal was deposited from a steel rod into a mold, an electric arc being maintained between the rod and the metal of the mold. Means were provided whereby the metal rod could be fed forward as it was consumed and a solenoid arrangement was provided for maintaining the arc length substantially constant. The ingots obtained under such conditions proved to be sound and free from shrinkage pipes. However, the cost of electrical energy in Russia in those days was very high and the process was commercially uneconomical.

The information obtained by Slawianoff in this work led to the application by him of the metallic arc to the uniting together of metal plates, the repairing of cracked and broken machines, etc.

Thanks to the work of Slawianoff we now possess a method of welding with metallic electrodes which at present is by far the most used of all arc welding processes.

Electric Arc

THE metallic welding arc is a phenomenon of great complexity. It is a combination of three distinct features; namely, conduction of the electric current, melting of the plate and deposition of the metal from the rapidly melting electrode. The first feature in itself is a complicated phenomenon, which can be understood better if we consider it after reviewing the accepted ideas on electric conduction in solid conductors and in vacuum tubes.

The electric current flowing through the solid conductor has been demonstrated by the experiments of Talman and Stewart to consist wholly of electrons. The positive ions form a rigid frame-work and participate only in the vibratory movements due to the thermal agitation. The whole space is occupied by the spheres of action of the atomic forces. And between atoms there is a continual exchange of the electrons. At any instant there is a number of electrons in transition from one atom to another. These dartings from one atomic system into another are especially numerous in good conductors, and the electrons which during that short flight do not belong to any atomic system are termed free electrons. In the absence of an electromotive force, these movements are equally distributed in all possible directions, and the resultant of those elementary currents is zero. When a difference of potential is, however, impressed on the conductor, these disorderly migrations acquire a certain orientation so that more electrons will be moving in the direction of the positive pole.

An idea of the number of moving electrons may be obtained if we will try to visualize the number 1.6×10^{19} which represents the number of electronic dartings during one second through the cross-section of the conductor when it is carrying a current of one ampere. However great this number may seem, it is not the total number of electronic dartings but only a difference between those directed towards the positive and negative poles.

The conduction through the space not occupied by the solid conductor is electronic only in case of extremely high vacuum. In this case the electrons shoot from the cathode in straight lines across the empty space between the comparatively few molecules present which in extremely high vacuum can be in the order of a hundred million per cubic centimeter. Since the molecules themselves are mostly an empty space with a few specks representing the central nuclei and outer electrons, the high speed electrons can also shoot through them without being stopped or deviated.

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1. Thomson Research Laboratory, G. E. Co., Lynn, Mass.

Presented at a meeting of the Lynn Section, A. I. E. E., Lynn, Mass., May 18, 1927.

When the cathode is cold the voltages necessary to produce such electronic currents would be of the order of millions of volts and the obtained currents expressed in milliamperes. In other words, for most purposes a space not occupied by either solid or gas of sufficient density is an insulator. There will not be any change in conductivity if a gas in a perfectly neutral state be introduced between the electrodes. The distances between the gaseous molecules, even if their number is increased to several billion of billions per cubic centimeter, are relatively so great that there cannot be any exchange of electrons as in solid conductors between the atoms and the space remains non-conducting. This, however, will cease to be so if the molecules acquire electrical charges.

Under usual conditions gases are subjected to various ionizing radiations such as the radioactivity of the earth, ultra violet rays and the electrons emission from the hot bodies and flames. In atmospheric air these factors determine a generation of two to three ions per second per cubic centimeter. However small the degree of ionization may be, the gas will always contain a few ions and free electrons. If an electron moving under the influence of applied difference of potentials with sufficient velocity encounters or passes very near one of the outer orbital electrons of an atom, the repulsive forces between them may be such as to detach the orbital electron from the atomic system, which then remains with a unit positive charge. The removed electron may either repeat the same process with the next molecule or attach itself to it, thereby communicating a negative charge. This removal or attachment of one extra electron to the neutral molecules is called ionization.

Electrons so produced and ionized atoms or molecules will also start moving in the direction of the electric force and if the potential gradient is sufficient, will acquire such velocity that their impact on neutral molecules will ionize these. This process of cumulative ionization in a very short time will produce a sufficient number of carriers to transmit from one electrode to another a considerable current. Under certain special conditions, the highly ionized gas column may acquire an electric conductivity comparable with that of a good solid conductor. It might seem strange that a gaseous column can be almost as good a conductor as a copper rod, yet if we remember that the conduction depends only on the number of suitable carriers and on the velocity with which they can move this apparent paradox disappears. Now to pass from conduction through ionized gas to arc conduction, we shall consider the effect of the temperature of the cathode. When the cathode is brought up by some means to a high temperature the electrons will be ejected from its surface into the gas in great numbers. These free electrons can be considered as ions and the gas containing such electrons as an ionized gas. The voltage necessary to move these free electrons towards the anode can be comparatively low. If the gas is at a very low pressure, the electrons will move in straight lines between the molecules. Only a very few of these electrons will be stopped or deflected by collision with molecules. In this case the current will be purely electronic. However, when the molecules are present in larger numbers the electrons (if moving with sufficient velocity) will ionize the gaseous molecules and the current will be carried by ionized molecules as well as by the electrons.

The method of producing the intense initial ionization in the case of an electric arc is by taking advantage of the above described property of certain materials to emit electrons at high temperatures. To draw the arc between the two electrodes, they are brought in contact and a current of sufficient magnitude is passed across the contact. The resistance of the contact, especially just before the moment of separation of the electrodes, is high enough to cause rapid heating of the tips of the electrodes to incandescence, with the result that numerous electrons are projected into the surrounding gas, so that at the moment of separation of the electrodes, the gas contains large numbers of free electrons which under the action of the established electrostatic field will move and impinge on the gaseous molecules.

Since the separation of the electrodes is done gradually, even with comparatively low voltages the potential gradient during the first moment will be sufficient to give the necessary acceleration to the free electrons which at the end of their free path will possess energy to ionize the gaseous molecules. The ionized molecules and electrons will move and impinge on the next neutral molecules but unless the potential gradient is sufficiently high, they will not acquire at the end of their free path a sufficient velocity and consequently will be unable to ionize the next set of molecules; therefore, the ionization will not continue. Since the distance between the electrodes continued to increase and the potential gradient to decrease, the current, after reaching certain magnitude, will fall to a lower value and finally stop altogether. But if the potential gradient during the separation of the electrodes be sufficient, the number of carriers will increase very rapidly until an appreciable current will flow between the electrodes which will produce rapid heating of gas. At higher temperatures the ionization occurs much more readily, so that as soon as the appreciable current flows, the ionization is more pronounced which again causes the current to increase. As soon as the cathode spot on the electrode is brought to a high temperature, a large volume of metallic vapor is sent into the stream which is easily ionized and will conduct practically the whole current. This is the arc conduction.

Since the drawing of the arc is done at a low temperature and the maintaining of the arc at high temperatures, the voltages necessary to strike the arc are always much higher than those used to maintain the arc.

This feature is taken advantage of in the design of a number of commercial welding generators which produce a high voltage only on open circuit. As soon as the arc is drawn, the voltage across the brushes automatically falls to a value only slightly higher than that of the voltage across the arc.

Since high temperature is essential to maintain easy ionization, any factor tending to cool off the electrodes or the arc stream will influence greatly the stability of the arc. If the temperature of the arc falls, the ionization of the materials in the arc stream does not take place as readily, so that the agent producing ionization must be more active. In other words, the speed with which the electrons and ions impinge on the neutral molecules must be higher which necessitates a high potential gradient; that is, higher arc voltage. One of the most powerful methods of cooling the arc core is by surrounding it with hydrogen, which at high temperature dissociates into the atomic state and absorbs large amounts of energy.

Atomic Hydrogen Process

This phenomenon of dissociation of molecular hydrogen at high temperatures into the atomic state was discovered by Dr. I. Langmuir[2] during his studies of the laws of heat losses from a heated tungsten filament in hydrogen at low pressures. Dr. Langmuir observed that above certain temperatures, the heat losses instead of being proportional to 1.9th power of the absolute temperature, are proportional to a much higher power which increases with temperature.

The following studies of this phenomena established that these abnormally high losses are due to the dissociation of molecular hydrogen into the atomic state. Step by step Dr. Langmuir discovered the temperatures of dissociation, degree of concentration of the produced atomic hydrogen, the energy absorbed by the dissociation, the chemical properties of the atomic hydrogen and the thermic effects produced by recombination of the atoms into molecules.

The atomic hydrogen possesses many remarkable properties which have been studied in the last few years by several investigators. Many chemical reactions impossible with molecular hydrogen take place when that gas is in the atomic state. The most stable oxides can be reduced into the metallic state. Substances which are usually considered as the most refractory materials can be melted by the flames of atomic hydrogen. And certain hydrogen compounds which formerly could be produced in very small concentrations, now may be obtained in 100 per cent concentrations. There are two methods of producing atomic hydrogen.

One discovered by Dr. Langmuir is by increasing the speed of the thermal agitation of hydrogen molecules until the forces between the two atoms composing the molecule are not sufficient to hold them together. They spring apart and by doing so absorb large amounts of energy from the source producing that thermal agitation. In this method all molecules subjected to the high temperature are being acted upon simultaneously. This is (if we can use such a term here) a "mass production."

The other way of disrupting the hydrogen molecule is by hitting it with a heavy atom, moving with high velocity. In this method the hydrogen molecules are dissociated one by one and only when shot with a swiftly moving atom. Using again a shop term, we can call it "piece work." However, Dr. Langmuir developed the first method which permits the production of atomic hydrogen in high concentration, which permits the use of atomic hydrogen not only as a special chemical regent but also as one of the most remarkable agents for transmission of thermal energy. To accomplish this, it was necessary to produce the atomic hydrogen not inside of a vacuum container, but in the open air. The method adopted by Dr. Langmuir consists in blowing a stream of molecular hydrogen through an electric arc maintained between two tungsten electrodes.

The temperature of the arc core is sufficient to produce complete dissociation of the whole mass of the gaseous layer in contact with it. The produced atomic hydrogen diffuses rapidly away from the arc core and recombines in the cooler regions into the molecular state, forming an extremely hot flame of a single gas which burns without oxygen. The evolved heat, of course, is the energy previously absorbed from the arc. It was found that the heat of formation of molecular hydrogen is equal to 98,000 calories. In other words, when the atomic hydrogen recombines to produce one cubic foot of molecular hydrogen (measured at N. T. P.), the amount of heat produced is 455 B. t. u This quantity is greater than that obtained by the combustion of one cubic foot of molecular hydrogen in oxygen. In the last case the amount of evolved heat will be only 316 B. t. u.

The greatest advantage of the atomic hydrogen resides not in the amount of energy transmitted but in the high potential at which that energy is delivered. In other words, the remarkable property of the atomic hydrogen is the temperature o its flame. Dr. Langmuir's calculations show that this temperature is at least 3717 deg. cent. One of the experimental confirmations of these conclusions is the fact that tungsten, the metal with the highest known melting point, can be melted in the atomic hydrogen flame but not in any other flame.

The importance of the temperature of the flame can be illustrated by the comparison of two combustible gases; one of which is acetylene and another is propane. The amount of energy produced by combustion of one cubic foot of acetylene is 1456 B. t. u. The corresponding value for propane is 2465 B. t. u.

2. Flames of Atomic Hydrogen, *General Electric Review*, March, 1926.

In spite of much lower heat capacity of acetylene, the temperature of its flame (about 3000 deg. cent.) is higher than that of propane (about 2100 deg. cent.) and the result of it is that the welding with that gas is much faster than with the latter.

One of the practical applications of the atomic hydrogen flame is for welding of metals. In this field it has received lately numerous applications on account of its two properties especially valuable for welding work; namely, the extremely high temperature of the flame and the reducing properties of the gas forming that flame.

As a welding tool the atomic hydrogen torch must be compared with the oxyacetylene torch. It has similar characteristics in that the most of the energy is produced in a comparatively small inner cone or fan where extremely high temperature is attained. This inner hot zone is surrounded by the flame of reducing gas with temperatures gradually falling to that of the outer mantle of the flame where the recombined molecular hydrogen is burning in contact with the air. The temperature of that part of the flame is something like 1000 deg. cent.

This gradual change of emperatures gives an extreme flexibility to the atomic hydrogen torch. It insures a perfect control of speed of welding and of the temperature of the molten metal in the weld. This last factor is of a paramount importance for welding in hydrogen atmosphere. This gas is only slightly soluble in molten iron ust above the melting point. But with a rise of temperature its solubility increases very rapidly. When the molten iron is overheated, it will absorb at least 15 times its own volume of gas (measured at N. T. P.). During the solidification most of that gas will be precipitated out and unless special precautions are taken, will form numerous blow holes.

However, if the welder follows the right technic by forming only a shallow pool of molten metal which insures a low temperature of the molten iron, hydrogen will be prevented from going into solution and the resulting weld will be perfectly free from gas pockets.

The atomic hydrogen torch embodies in itself all the necessary conditions not only to transmit from the arc into the plate any desired amount of energy, but also to do it at a very high speed. The high speed of recombination of the atomic hydrogen into the molecular state is determined by the steep gradient of temperatures and also by the catalytic action of the metal in the weld.

This recombination of the atomic hydrogen at the surface of the liquid metal in the weld to a certain extent replaces he oxidation reaction always present when the welding is done in air. This reaction supplies the necessary auxiliary heat to keep the surface of the solidifying metal in the molten state long enough to permit the absorbed gases to escape freely.

The a-c. arcs used in the atomic hydrogen process are usually two or three centimeters in length bent in a shape of a fan between two tungsten electrodes placed to form a "V". The voltage drops at the surface of the electrodes, which correspond to anode and cathode drops in d-c. arcs, are equal to about 18 volts each. With the usual arcs of about 100 volts, the 36-volt drop at the surface of the electrodes, therefore, represents one-third of the total arc voltage, so that two-thirds of the energy absorbed in the dissociation of hydrogen into atomic state comes from the long arc core. The usual arc voltage is about 100 volts and the open circuit voltage of the welding circuit is seldom less than three or four times that value. The energy absorbed by the weld, of course, is that which comes from the arc; the atomic hydrogen plays the role only of an exceptionally efficient transmitter.

The energy evolved by burning the molecular hydrogen in contact with the air, serves only to raise slightly the temperature of the plate outside the weld but does not affect appreciably the weld itself. Most of that energy is radiated into surrounding space.

The Shielded Arc Process

While the work on atomic hydrogen was proceeding in the Schenectady Laboratory, the writer was engaged in the Lynn Laboratory on the development of an improved method of the arc welding with metallic and carbon electrodes.

Since the accepted explanation of brittleness in arc welds was the presence in the weld of oxides and nitrides of iron, the first experiments were conducted on welding in gases other than those composing the atmospheric air. The first experiments were conducted on welding in carbon dioxide, superheated steam and illuminating gas. Then, without any knowledge of Dr. Langmuir's experiments with atomic hydrogen, the writer came to the conclusion that it is hydrogen which must give the desired results. The experiments immediately confirmed this view. The welds produced in that gas proved to be perfect y ductile and to possess a high tensile strength. Furthermore, it was found that the apparent resistance of the welding arc in hydrogen is more than twice that of the same arc in air. Because of the desirability of rapid deposition of the metal, the welding arc must have a definite short length. The increase of the apparent resistance of the arc without increase in length is most welcome as it makes the arc almost twice as efficient as a device for the transformation of the electrical energy into the thermal form.

The anode and ca hode voltage drops of an iron welding arc of 100 amperes maintained in hydrogen atmosphere were found to be each equal to 16 volts. The voltage drop across the arc stream for an arc of 1/8 inch does not exceed 5 volts, so that the total voltage across the arc of 1/8 inch in length is 37 volts. The usual arc voltage of the welding arcs of the same length and current intensity maintained in air is about 18 volts.

This abnormal apparent resistance of the arc in hydrogen, the writer at that time attributed to an exceptionally high coefficient of heat conductivity of that gas. Indeed the heat conductivity of air is 0.5×10^{-5} and that of hydrogen is 3.17×10^{-5} calories per centimeter per second per deg. cent. In other words, it was thought that the high voltage of the arc is due to a mere cooling of the arc by hydrogen in its molecular form.

At a later date, to check up this assumpt on, the writer repeated the same experiments with the arcs in hel um. This gas has also an exceptionally high coefficient of heat conductivity which is even slightly higher than that of hydrogen; namely, 3.39×10^{-5}. The experiments, however, showed that the arc voltage in that gas is lower even than in air. Since the coefficients of diffusion of hydrogen and helium are about the same and the temperature of the arc core in both cases probably does not differ materially, the only explanation of difference in the arc voltages was that the hydrogen, being a diatomic gas, was dissociated into the atomic state while the helium, being a monatomic gas, remained unchanged by the extreme temperature of the arc.

These experiments have an interest only as illustration of various ways of investigation. The quantative determination of the amount of atomic hydrogen produced cannot be based on such experiments. They only demonstrate the fact of the dissociation of hydrogen into the atomic state and that it affects very markedly the anode and cathode fall.

These two quantities are determined by the concentration of the ions of one sign at the surface of the electrodes. If the production of the ions of the other sign in the first gaseous layers next to the electrode is slowed down, the electrostatic charges of the incoming ions will determine a very steep potential gradient. The dissociation of hydrogen into the atomic state cools off the surface of the anode and cathode and, therefore, reduces there, the speed of ionization and emission of thermions. The role of atomic hydrogen in the shielded arc process can be compared with the most effective means of cooling the electrodes.

Of course, the atomic hydrogen produced undoubtedly affects also the quality of the weld, making it more free from oxides. This last action, however, is not as important as that which increased the efficiency of the arc, since in the shielded arc process, the weld is fully protected by a large volume of the molecular hydrogen which at the high temperature of the arc is also one of the most energetic reducing agents.

The Deposition of Metal

The transfer of the metal from the electrode to the plate can be either purely ionic or mechanical. In the first case the metal is rapidly vaporized from the electrode, enters the arc and after being ionized is moved across the arc to the surface of the positive crater where it regains its state of neutral atoms and condenses as a vapor on the surface of the crater. The speed of motion of gaseous ions is very high so that large quantities of metal can be transferred from the electrode to the weld in a very short time. The hypothesis of transfer of the metal in the state of vapor has been advanced by Professor Slocum.[3] This type of metal transfer is observed only with long arcs.

The writer's experiments indicated that the temperature of the anode is the determining factor in the ionic transfer of the metal in the welding arc. If an arc of 125 amperes and 60 volts be maintained in hydrogen between a cold plate and ⅛-in. Armco pure iron electrode, the transfer of metal will be mostly mechanical. The tip of the electrode will be liquified and the large drops of metal will be periodically falling down on the plate. The vapor stream from the negative electrode will enter the arc, but there will not be appreciable condensation of that vapor on the plate If, however, the positive crater be allowed to establish itself on the plate and the temperature of the molten metal in the crater rises above a certain limit, then the arc will become very stable and practically the total amount of metal will pass through the arc in a state of ionized vapor. The speed of "vapor deposition" of metal is about the same as that wh ch would be with the short arcs of the same current density when practically the total amount of metal is passing through the arc in the liquid state. However, in usual practise, the arc length is so short that the intense radiations from the positive crater affect not only the surface of the negative crater but also the whole tip of the electrode to a considerable length. This results in rapid melting of the tip of the electrode which is in more or less plastic state to a distance of three or four millimeters from the negative crater. This condition determines an entirely different mode of transfer of metal across the arc. The wire used as electrodes always contains a large amount of occluded gases. The actual volume of occluded gases depends on the method of manufacturing of the wire and in certain instances may reach many times the volume of the metal.

The amount of gas which the metal can hold in the occluded state depends on the temperature. At the temperature of red heat, most of the gases are expelled from the metal. Since the tip of the electrode is in molten state, it is mechanically the weakest point and the gases escape in that direction which results in periodical rupture of the liquid surface of the tip of the electrode and projection of it into the direction of the positive crater. If the arc is very short, this ruptured part of the tip of the electrode short-circuits the arc. In other words, it bridges the tip of the electrode with the positive crater. As soon as the globule touches the liquid surface, another set of forces comes into play; namely, the surface tension of the molten metal. Now the globule is pulled towards the liquid by the surface

3. The Welding Arc. *Welding Engineer*, January, 1921.

tension and so breaks the contact with the electrode. If the time of transfer was short, the temperature of the ionized gases was not affected appreciably so that the arc can be readily restarted. The experimental proof of this mechanism of transfer of molten metal across the welding arc was furnished by many investigators amongst whom we must name Prof. Hudson[4] who advocates the theory of liquid transfer of metal determined by the expulsion of the gases, and Mr. O. H. Eschholz[5] who demonstrated that even without the explosive action of gases, the metal can be transferred through the action of the forces of the surface tension. However, the writer is of the opinion that both types of forces are responsible for the transfer of the metal in the short welding arc.

Physics and Chemistry of the Crater

In the case of arc welding with a metallic electrode, the positive crater is established on the plate itself. This is the most efficient method of transmitting the energy of the arc into the plate. In this case not only the metal is subjected to the radiations from the negative crater and the arc core, but it is also the subject of the most terrible bombardment by the electrons and ions rapidly moving towards the anode. The velocity of gaseous ions in the arc core is not definitely known but it may be expected to be very high. Furthermore, the condensation of the gaseous ions on the liquid surface of the crater is accompanied by the evolution of the latent heat of evaporation of electrons and gaseous atoms. This last factor explains the difference in the calorific effects at the anode and cathode of the arc in spite of the fact that the anode and cathode potential drops, as in the case of the iron arc in hydrogen, are the same. The surface of the metal is heated so rapidly that the heat has no time to be conducted away through the thickness of the metal. Therefore, the metal around the foot of the arc core is liquefied and forms a shallow molten pool. The metal in this molten pool is a subject of several actions. First, the rapidly falling metallic globules splash the molten metal so that the surface of the crater is continually swept by the waves running from the center of the crater to the periphery. Secondly, the molten metal, being free to move, is repulsed from the foot of the arc by the electromagnetic interaction of the currents carried by those parts of the arc and moves towards the edges of the molten pool, forming a sort of a shallow cup or a crater.

The absorption and evolution of gases in different parts of the crater is a factor of paramount importance. The accurate tests conducted by Dr. Baraduc-Muller,[6] who was experimenting with the masses of molten steel weighing 11,000 pounds, demonstrated that molten steel may hold in solution very large amounts of gases. For instance, the volumes of hydrogen, carbon monoxide and nitrogen occluded in one cubic foot of molten Bessemer steel are respectively equal to thirteen, eight and five cubic feet (measured at N. T. P.).

The writer's experiments with hydrogen, helium, argon, carbon monoxide and nitrogen occluded in the molten part of the crater gave about the same figures and indicated that these gases are precipitated out from the molten steel when it is still fluid. The observation of the large craters of the powerful arcs burning in different gases reveals that all these gases are absorbed in the hot part of the crater and evolved in a form of a stream bubbles coming to the surface of the molten metal in cooler parts of the crater.

This continual process of absorption and evolution of gases is equivalent to an energetic washing of the molten metal with hot gas. The occluded gases may react with the metal and form nitrides, oxides, hydrides or may simply be held in solution and be partly precipitated out during the solidification. At any rate the large amounts of absorbed and later evolved gases have a very great bearing on the soundness of the deposited metal and the number of blow holes which it may contain.

When the arc is maintained in air, the fundamental chemical reaction in the crater of the arc is oxidation. Oxygen of the air coming in contact with the molten metal reacts almost instantaneously and forms FeO which is gradually dissolved in the mass of the metal. The excess of that oxide floats on the surface in a form of a slag and being further oxidized during the freezing of the metal to Fe_3O_4. The oxidation or burning of the surface layer of the molten metal in the arc crater has a determining influence on the number of gas inclusions in the weld metal. As has been demonstrated by the writer's experiments on welding arcs in argon-oxygen mixtures,[7] the amount of heat produced by the oxidation reaction is sufficient to maintain the surface of the freezing metal near the edge of the crater in molten state long enough to allow all the gases to escape freely and leave the weld metal free from blow holes.

When the deposition of the metal is done in reducing or neutral atmosphere, this reaction is suppressed and unless special precautions are taken, the weld metal will contain numerous blow holes.

It may be pointed out here that in the atomic hydrogen process, the recombination of the atomic hydrogen into the molecular form at the surface of the weld metal provides a source of large amount of energy. In this way the atomic hydrogen process not only suppresses the deleterious action of oxidation but also provides means to replace the important and desirable influence of that reaction by a new reaction which takes

4. A Theory of Metallic Arc Welding, *Journal of Am. Welding Society*, October, 1919.

5. Metal Deposition in Arc Welding, *Electrical World*, June, 1920.

6. The Gases Occluded in Liquid Steel, *Iron and Steel Institute Carnegie Scholarship*, Memoir, 1909.

7. Oxidation of the Arc Crater, *Journal of Am. Welding Society*, December, 1926.

place of the old one. In the shielded arc process, other means are used to assure the prompt expulsion of the occluded gases.

Welding in Mixed Gases

The development of the shielded arc process extended also to the making of welds in mixtures of hydrogen and carbon monoxide according to the ideas of Prof. E. Thomson.

The tests demonstrated that the metal deposited in that atmosphere possessed about the same ductility as those produced in pure hydrogen. Furthermore, it was found that the arc in water gas is much more stable than in hydrogen and does not necessitate the open circuit voltage even for welding with comparatively low currents, higher than used for standard work of welding in air.

Other tests were made with various gaseous mixtures. In conjunction with Professor Thomson the author found that not only various mixtures of hydrogen and carbon monoxide could be used for welding work, but that certain organic liquids such as methanol and denatured ethyl alcohol when vaporized will serve the same purpose as the pure hydrogen.

Working in conjunction with Dr. Langmuir, the author also carried out a series of tests which demonstrated that for certain purposes nitrogen mixed with certain amounts of hydrogen gives welds of superior quality. It should be mentioned here also that the mixture of hydrogen with argon was suggested to the writer by Mr. P. K. Devers.

The work conducted on welding in various gases resulted in the development of practical means of producing these gases easily and at a low cost from various organic and inorganic compounds such as alcohols, ammonia, propane, etc. Since these compounds are liquids or liquefied gases, the question of storage and transportation has also been solved. This can be made clear if we consider that one gallon of methanol will give on vaporization and dissociation in the arc over 240 cubic feet of gas. The development of welding in alcohol vapors should be especially emphasized as one of the most practical solutions found in this laboratory of the problem of storage and cost of the most suitable gas for welding by the shielded arc process which is water gas.

When instead of pure hydrogen, the shielding gaseous atmosphere is provided by the gaseous mixture of carbon dioxide with propane or the vapors of alcohol, the function of the arc is not only to liberate sufficient amount of energy to melt the metal but also by dissociating the gaseous raw materials, produces a suitable mixture of hydrogen with carbon monoxide. The electric arc here becomes not merely a source of heat but also a chemical laboratory.

If we try to visualize all that is happening in the small space occupied by the arc, all the different chemical reactions, transformation of electrical energy into thermal form, absorption and evolution of gases and the deposition of metal, one begins to wonder how it is possible for the welder to take care of all these complicated factors. The answer is that they take care of themselves. If the conditions are regulated rightly, all these processes are entirely automatic and the man has to watch only the needle of the meter.

After going through this description of the atomic hydrogen and the shielded arc processes, one may ask, "What is the purpose of this development? What is all this for? Is it easier to use a combination of the electric arc with the gas instead of using each of these factors singly?"

The answer to the last question is "no." Of course, the combination of several factors necessitates better technique and more accurate adjustment of all the conditions. But what is complicated today will be a simple thing tomorrow.

It is simpler to make a lamp with the tungsten filament in the vacuum than a combination of the same filament and the gas. But who wants now the older and simpler type of the incandescent lamp? The present arc welding processes are all right and give excellent results in every field of their applications. But so did the rivet thirty years ago.

There was a time when no one dreamed of using anything but pure wrought iron. Then there came an age of iron-carbon alloys; that is, of steel. And now we are entering the era of alloy steels. Most of those steels contain such easily oxidizable elements as chromium. And unless the weld is protected by a reducing atmosphere, the results on welding such materials are not satisfactory. It is in this field that the new processes probably will find their best applications.

The electric arc and the gas flame will, in the future, replace rivet cutting tools and the foundry mold. Amongst innumerable fields of applications, there will be demand for every kind of welding and cutting processes. The described processes will not replace any of the existing processes but simply assume their place of usefulness amongst the older brothers and do the job which cannot be done without their help.

STANDARD GRADES FOR CRUDE RUBBER

The Rubber Division of the Department of Commerce, in a circular recently issued, announced adoption by the Rubber Association of America of a new set of official type samples of crude rubber to serve as a basis for transactions between sellers of rubber and American rubber manufacturers.

These samples are said to be identical with the new type samples recently adopted by the Rubber Trade Association of New York except that they also include packing specifications.

It is the feeling of officials of the Department that uniform international grades of rubber would be for the good of the entire industry throughout the world as well as in the interest of American trade. The description of new American type samples was issued in detail.

The Interpolar Fields of Saturated Magnetic Circuits

BY TH. LEHMANN[1]

Non-member

Synopsis.—*In this note, the question of the effect of assuming infinite permeability in the iron on the accuracy of calculations of the interpolar fields in electric machines is studied.*

One can do this very easily by replacing the saturated by non-saturated poles, covered by an infinitely thin sheet of current giving the same tangential component of the field along the surface of the iron. The field produced by this sheet of current, then, represents the difference between the exterior fields of the saturated circuit and of the non-saturated circuit.

In addition to this indirect method of estimating the influence of saturation, the sketch of the field between the poles and in the air-gap can also be directly developed by determining with the aid of the differential field, the point of indifference of the saturated circuit. A comparison of sketches obtained in this way shows that, for the same useful flux, the interpolar fields are almost the same in both cases. From these sketches and others which will appear shortly in the Revue Generale de l'Electricite, it is evident that the sketches and functional curves given by Messrs. Stevenson and Park, and Wieseman, in their very valuable work, can still be used even though the poles are saturated.

Introduction

SUPPLEMENTING my discussion of the very interesting papers presented by Messrs. Stevenson and Park, and Wieseman, at the last Mid-Winter Convention of the A. I. E. E., I should like to show briefly how, from the sketches of lines of force given by these authors, the distribution of the interpolar field can be obtained when the poles or the teeth are saturated.

I have chosen for this the magnetic circuit of a d-c. dynamo which has open armature slots. First, by assuming that the iron has infinite permeability, the sketch in Fig. 1 is obtained with four lines of no work, or gradients, which outside of the coil become lines of equipotential. This process of development is well known. In this case, the area of the coil has first been subdivided into four equal parts, and the last one of these, at the top, into eighths and sixteenths, etc., which makes it possible to see at a glance that each gradient[2] encloses that fraction of the total area which corresponds to its order. This is not sufficient, however, to obtain the exact position of the point of indifference[3] toward which the gradients converge and where the field is zero. It is necessary to make sure at the same time that the reluctances $R_1, R_2, R_3 \ldots$ of the parts of the same tube from one pole to the other are proportional to the ampere-turns $I\,n_1, I\,n_2, I\,n_3 \ldots$ enclosed by the gradients which cut off these portions of the tubes; otherwise the distance of the point of indifference from the side of the coil might vary from 1 to 2.

It is therefore necessary to check the relations $R_1 : R_2 = I\,n_1 : I\,n_2$, etc., as has already been shown under a different title in the *Revue Generale de l'Electricite* of September 22, 1923, p. 397.

When a portion of the tube is situated completely within the current-carrying region, the ampere-turns $I\,n_1$ included between the gradients which cut off that portion, are counted from the point of indifference to the line of force which forms the median of the portion of the tube under consideration. But if the portion of the tube falls partly in the interior and partly outside of the current-carrying region, it is preferable to count the ampere-turns $I\,n_1$ from the point of indifference to the first boundary line of the tube and add to that

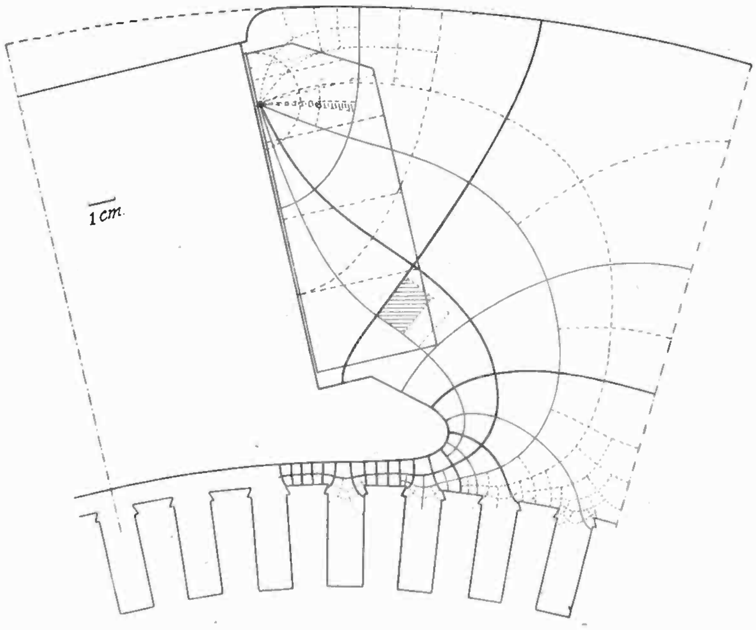

Fig. 1—Sketch of Interpolar Field of Non-Saturated D-c. Dynamo

value half ampere-turns contained in the portion of the tube itself.

Whenever the conductors in the portion of the tube form a rectangular section abutting against the two limiting lines of force, this reduction is applied, no matter what the thickness of the section, in the direction of the lines of force.

But when the eddy section does not cover the whole width of the tube from one line of force to the other, but only a fraction (n/m) of this width, it can be shown that

1. Consulting Engineer, Urmatt (bas-Rhin) France.
2. Called "lines of no work" by Stevenson and Park.
3. Called "kernel" by Stevenson and Park.

it is necessary to deduct the ampere conductors confined in an elementary tube having the width $(n/2\,m)$. For example, one should deduct 3/8 of an eddy section that covers transversely only 3/8 of the width of the tube, regardless of the length of the section.

Finally, in the case where the contour of the coil cuts the tube obliquely, we can employ this same method by using judgment in replacing the oblique eddy zone of the tube by a rectangle of the same area, but of proportions so as to touch the non-turbulent zone as little as possible.

The magnetic field outside the field coil is Laplacian, and can be determined by subdivision into tubes of unit reluctance (curvilinear square tubes), according to the usual method. The sketch is commenced by full lines which are subdivided only in the regions where estimation of the elementary tubes would not be sufficiently accurate otherwise. I am inclined to think that it is not advisable to commence the sketch with

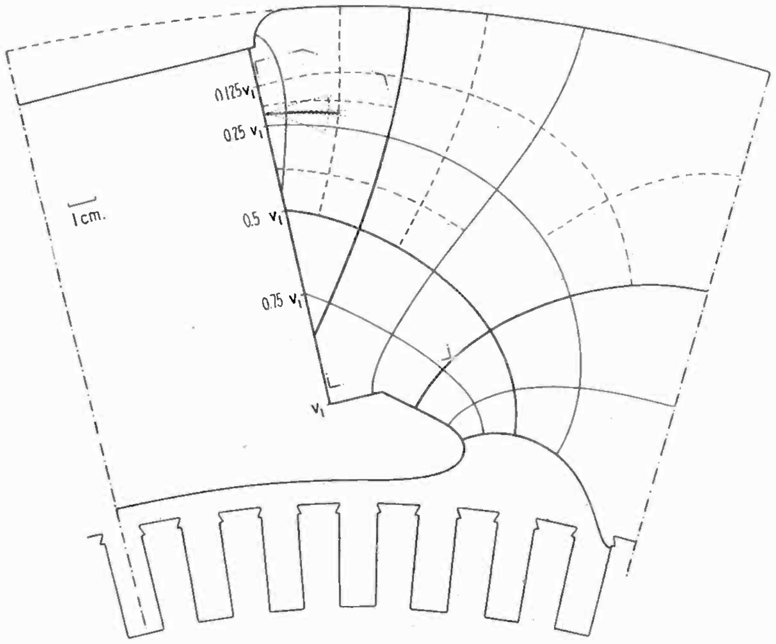

Fig. 2—Isometric Sketch of Additional Field Caused by Saturation of Poles

Assumed to be generated by an equivalent current sheet.

too fine a subdivision, which uselessly increases the necessary sketching and renders the localization of errors more difficult. The larger subdivision has also the advantage that, in rectifying the errors, account can more easily be taken of the effect of local retouching on the rest of the sketch which has already been traced.

The Additional Interpolar Field Caused by the Saturation of the Poles

Fig. 1 represents a sketch obtained in this manner. Now, assume that the pole is saturated in such a manner that, for the same useful armature flux, the pole core absorbs one-third of the total field pole m. m. f. $4\,\pi\,i\,n$, so that the difference of potential caused by the saturation of the pole will be

$$v_1 = \frac{4\,\pi\,i\,n}{3}$$

where the current i per turn is now in C. G. S. units. In Fig. 2, let us mark between the base and the top of the pole the points $0.125\,v_1$, $0.25\,v_1$, $0.5\,v_1$, and $0.75\,v_1$, calculated with the aid of the lines of flux in Fig. 1, and retouched as follows wherever necessary.

It has been shown in Sections III and IV of the mentioned article, that the field outside the iron will remain unchanged if the saturated core is replaced by a non-saturated core covered with an infinitely thin sheet of current. The current j per unit length must satisfy the relation:

$$4\,\pi\,j = \frac{\partial v}{\partial x}$$

in such a way that at the height x of the pole measured from its base, one will have:

$$v_x = 4\,\pi \int_0^x j\,d\,x$$

where v_x designates the superficial potential at this point caused by saturation. This equivalence, it is well understood, cannot be extended to the field in the interior of the iron, in which we are not interested here.

On account of this, the problem can be considered as follows. We can consider the interpolar field as resulting from the superposition of fields generated by the actual current in the field pole coil and by the counter-magnetomotive force of a sheet of current corresponding to the actual saturation, assuming in both cases that the iron is infinitely permeable. It is sufficient, therefore, to superpose on the sketch of Fig. 1, which was obtained for $\mu = \infty$ in the iron using the field current which would be required for the saturated pole, another field produced by the sheet of current, also calculated for $\mu = \infty$ in the iron. The sum of these two fields will give us the actual resulting field in the interpolar space and in the air-gap when the core of the field pole is saturated. If the field spider or yoke is also saturated, the sheet of current would naturally be prolonged along its surface.

The sketch corresponding to the sheet of current is very easy to secure because it is entirely Laplacian and the starting points of the equipotential planes $0.75\,v_1$, $0.5\,v_1$ . . . are known in advance, and in addition, the lines of force in the air-gap near the neutral zone differ only slightly from those of Fig. 1. Generally, such a sketch requires only a few minutes.

But this is not all. We gain, at the same time, a method of predetermining the kernel, or point of indifference, when the pole is saturated.

Utilization of the Difference Field for the Pre-Determination of the Point of Indifference

Since only equal and opposite fields annul each other, it is only necessary to search for the neighborhood where the gradients have the same direction and where the fields in Figs. 1 and 2 have the same intensity. Since the point of indifference must be in the interior of the coil, we notice immediately, when superposing Figs. 1 and 2, for example, against a window pane, that the gradients of Fig. 1 are tangent to the potential lines

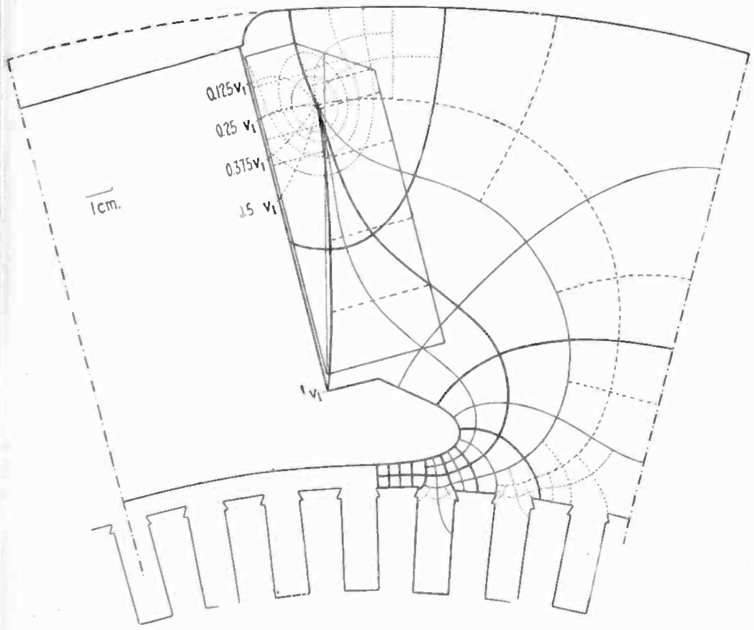

Fig. 3—Sketch of Interpolar Field of Dynamo Shown in Fig. 1, When Pole is Saturated

The point of indifference has been moved toward the interior of the field coil. The ampere-turns on the left of the gradients issuing from the points v_1, are consumed in the pole; and those to the right of these gradients are absorbed by the air-gap.

in Fig. 2 in the narrow slice which has been cross-sectioned vertically; see Fig. 1. The tangency continues far enough so that it is well to mark off a slice by the two gradients of Fig. 1, which coincide with only slight deviation with the potential lines of Fig. 2. It is only necessary now to compare the intensities of the fields. In Fig. 2, we see that the potential line on which the new point of indifference should be found is located in the square, the bases of which have a difference of potential $v_1/8$, and the lines of force a length of 1.95 cm. Assuming that the current density i_0 is $1/4\,\pi$ C. G. S. units the magnetomotive force of the whole field coil will be, for the scale of Fig. 1, 51 C. G. S. units, and that of the fictitious sheet of current 51/3 C. G. S. units, so that in the square tube under consideration in Fig. 2, the field H expressed in C. G. S. units is:

$$H = \frac{51}{3} \cdot \frac{1}{8} \cdot \frac{1}{1.95} = 1.10 \text{ C. G. S. units}$$

If one compares in Fig. 1 the curvilinear sector formed by the gradients, which embrace the fourth and the eighth part of the section of the coil, to a circular sector, the radius of such a circular sector must be, according to a well-known relation, $r = \dfrac{2\,H}{4\,\pi\,i_0}$, and remembering that $i_0 = \dfrac{1}{4\,\pi}$ C. G. S. units is the assumed current density, we then have:

$$r = 2\,.\,1.10 = 2.20 \text{ cm.}$$

and since the center of the equivalent circular sector falls one mm. behind the point of indifference, of Fig. 1, the new point of indifference will be found 2.10 cm. distance from the old one on the curved line bisecting the small cross-sectioned slice of Fig. 1.

Direct Development of the Interpolar Sketch When the Poles are Saturated

Since we now know the point of indifference when the pole is saturated, we can easily develop the sketch of the interpolar field shown in Fig. 3, by dividing the area of the coil in the ratio 1:3 by a line which starts from the lower left corner of the coil. In this particular case, the point of indifference will be to the left of this line, and it is evident that the gradient which starts from the point v_1 of the pole core must be a little further to the right than the dividing line. The curve of this gradient

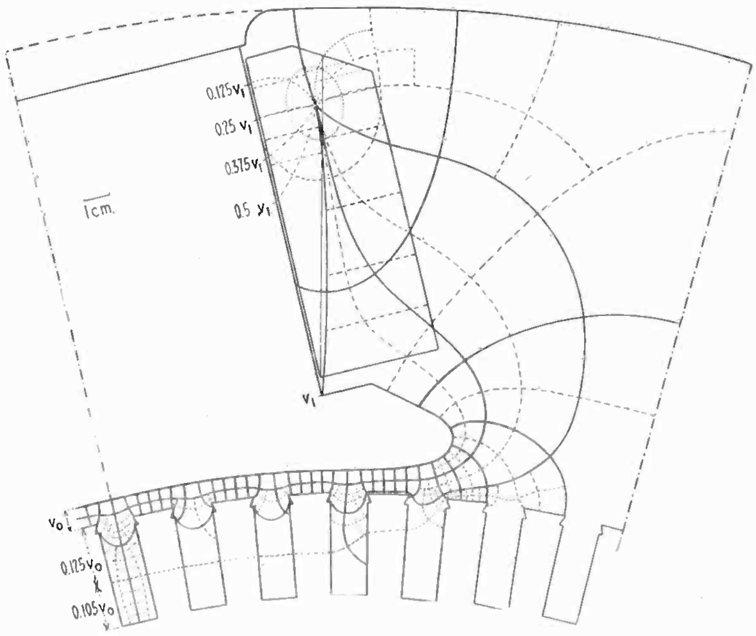

Fig. 4—Lines of Force and Gradients When Poles and Armature Teeth are Saturated

The ampere-turns to the left of the gradients starting from the points v_1 are absorbed by the pole; and the ampere-turns to the right by the air-gap and the armature teeth.

will be given to us by the condition that on both sides of it the tubes of the same parameter must join without discontinuity, which makes it necessary to move the horizontal dotted lines which divide the coil in aliquot fractions sideways from this gradient until the proper concordance is obtained. The gradients which start from the pole core are easy to trace, since they join the points v_1, 0.5 v_1, 0.25 v_1, and 0.125 v_1, with the point of indifference.

Unfortunately, the same line of force was not taken as the starting point in Figs. 1 and 3, but one can, nevertheless, recognize that the total interpolar flux is slightly *weaker* for the saturated pole than for the non-saturated pole for the same useful flux (in spite of the fact that there were 50 per cent more ampere-turns in Fig. 3); but the difference is not more than 1 per cent of the useful flux.

Case Where Poles and Armature Teeth are Saturated

In Fig. 4, the case has also been treated where the pole absorbs a third of the total ampere-turns, while the armature teeth consume 23 per cent of the ampere-turns consumed in the air-gap, as is indicated by the numbers 0.125 v_0 and 0.105 v_0, noted alongside the first tooth. The general appearance of the lines of force is, so to speak, the same as in Fig. 3, but the interpolar leakage flux is larger, since the ampere-turns necessary for the armature and the air-gap have become larger for the same useful flux.

Generalization from the Superposition Process of Section II

Finally, it may be asked if one could not also obtain the point of indifference of Fig. 1 with the aid of the air field due to the field coils, for example? This is, in fact, possible, as we will soon show in the *Revue Generale de l'Electricite*. Thus, we are led to the following statement. The difference field between two interpolar fields generated by the same coil and the same currents along a given contour is always a Laplacian field, whether the contour is formed by saturated mediums or not, and even though the contour is simply imagined in an entirely air medium.

This principle is especially serviceable when it is necessary to determine the resulting field generated by several coils, as in the case of a d-c. dynamo having commutation poles, for example. The resulting fields in the slots when the teeth are highly saturated can be determined very well by this method. It is necessary to plate the walls of the teeth with sheets of current, giving the same tangential potential gradient along the teeth walls as the resultant field.

The principle of superposition of Section II can also be applied to space. It is sufficient to make 4 π times the vector of the density j of the superficial currents (in C. G. S. units) equal to the negative of the vectorial product of the normal exterior unit vector n and the field vector H at the exterior surface, as shown by the equation:

$$4 \pi j = - [n, H]$$

Conclusions

Summing up, it may be said that the interpolar sketches developed on the assumption that $\mu = \infty$ in the iron are generally sufficiently exact for all practical purposes, provided the interpolar flux is obtained from the number of field ampere-turns necessary for the air-gap and the armature.

When only the poles are saturated, the necessary correction is hardly ever more than 1 per cent of the useful flux, for the same potential difference between the pole tips.

But one can also develop directly the sketch in the air-gap, in the interpolar space, and in the slots, when the magnetic circuit is saturated. It is then advantageous to determine the additional Laplacian field caused by the saturation, which makes it possible to find the exact position of the points of indifference. As soon as these points are known, sketching the field presents practically no further difficulty.

The author wishes to express his gratitude to A. R. Stevenson, Jr., for translating this paper.

PROSPECTIVE LEGISLATION FOR 70th CONGRESS

The long session of the 70th Congress convenes on Monday, December 5th. A survey of important legislative matters which will come before this Congress, according to the leaders, shows that there are many items of interest to the engineer. These include flood control, railway consolidation, provisions for the public building program, the assembling of public works functions in the Department of the Interior, the important engineering projects such as Boulder Dam, Columbia River Basin projects, Muscle Shoals, and River and Harbor improvements.

Other subjects of indirect interest to engineers which are said to be slated for early consideration are tax reduction, farm relief, national defense measures, including the extensions for Navy construction, and of course, the regular annual appropriation measures carrying many items of engineering interest.

Deficiency appropriations which were not acted upon by the last session and which have caused some branches of the Government considerable embarassment since the beginning of the fiscal year will receive special attention.

GERMANY PRODUCES NEW ALLOY

Production of "Aldrey," a new aluminum alloy, developed for electric power lines and said to have tensile strength that does not interfere with its electrical conductivity, has begun in Germany and production licenses have been granted for both Germany and Austria, the American Consul at Frankfort-on-Main, has reported to the Department of Commerce.

The claims for the new alloy state that it was developed especially for electric power lines for which it is suitable because of its tensile strength and electrical conductivity.

The production of this alloy is the result of a studied economic policy in Germany to divest the industries of the country of dependence upon primary foreign materials.

Abridgment of

Tandem System of Handling Short-Haul Toll Calls In and About Los Angeles

BY F. D. WHEELOCK[1] and E. JACOBSEN[2]

Associate, A. I. E. E. Associate, A. I. E. E.

INTRODUCTION

IN telephone practise there are, broadly considered, two distinct methods of completing telephone calls between central offices, one by means of direct trunking and the other by means of tandem trunking. The fundamental difference between these two methods may be best obtained by referring to Fig. 1. It will be noted that direct trunking, as the name implies, requires a separate group of trunks from any one office to every other office, whereas tandem trunking provides for a single group of trunks from each office to a centralized point, known as the tandem center or office, at which are means for switching together any desired combination of trunks. Under the direct trunking plan, 30 groups of trunks are required to interconnect completely the six offices illustrated, while under the tandem trunking arrangement only six groups are necessary. The tandem trunking plan has the advantage that the trunk groups are comparatively large and therefore can be used more efficiently. It is obvious that the advantages of tandem trunking become very marked as the number of offices to be interconnected increases.

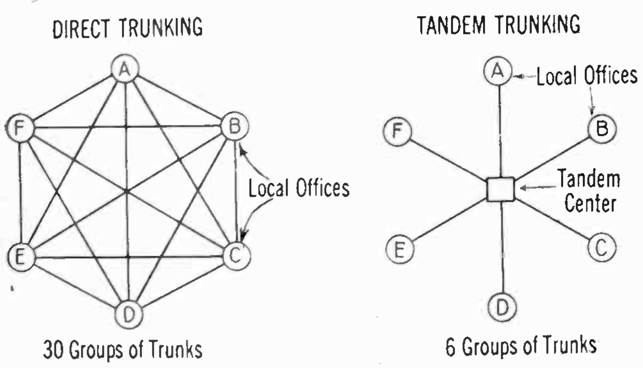

FIG. 1—TRUNKING PLANS

A great many tandem systems are in operation today where the switching at the tandem office is done manually. There are a few installations where a moderate amount of tandem switching is done automatically. The first tandem trunking system to employ on a large scale, apparatus for switching which is under the control of dials located at the various operators' positions tributary to the tandem office, was recently installed at Los Angeles to handle the short-haul toll traffic within a radius of approximately 40 mi. This system is known as a dial tandem system.

It is the purpose of this paper to describe the Los Angeles dial tandem system. It should not be inferred that a system similar to the one installed in Los Angeles should necessarily be regarded as suitable for other large cities, as there were certain conditions in this area which made this type of installation particularly desirable.

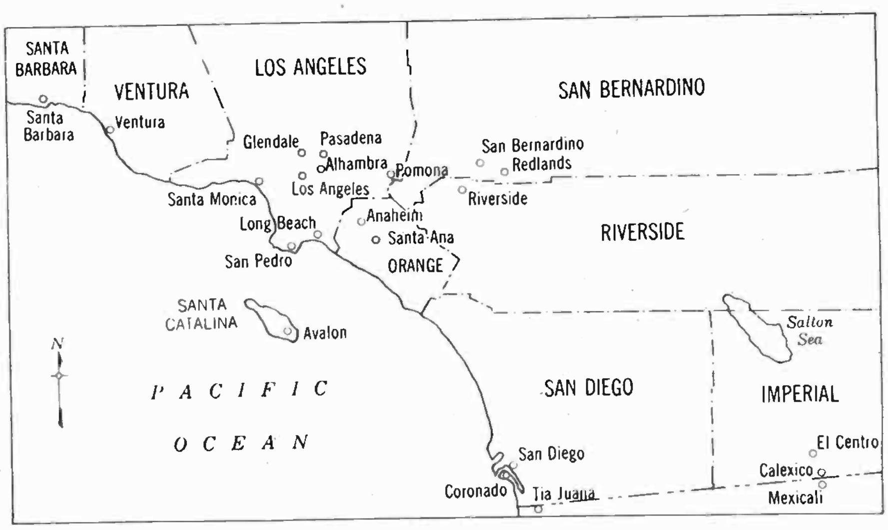

FIG. 2

CONSIDERATION WHICH LED TO THE INSTALLATION OF THE DIAL TANDEM SYSTEM

The abnormal demands for telephone service between cities and communities have more than kept pace with the growth in population. The facilities at times have been taxed to the limit and a few years ago it became evident that new methods of handling the short-haul toll traffic must be devised. The toll board method is adequate for long distance toll traffic, but a faster method was required for moving the unprecedented increase in short-haul traffic.

The requirements for a more rapid and adequate method for handling the short-haul toll traffic have caused the telephone company to focus its efforts on furnishing short-haul toll service comparable to local service, and in 1923 a study was made of the application

1. Southern California Telephone Co., 940 S. Olive St., Los Angeles, Calif.

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of tandem systems for handling the station-to-station traffic around Los Angeles. Step-by-step tandem and straightforward manual tandem systems were studied, both proving to be more economical and faster than the toll board method, the former being more economical than the latter. Decision to proceed with the Los Angeles tandem system project was made as soon as the results of the study were determined; and the engineering work for specific installations was started immediately.

In 1924, switchboard position equipment was placed in service in various Los Angeles central offices to care for the necessary manual services for dial stations which provided a practical means for handling short-haul toll calls originating from dial stations. In the same year

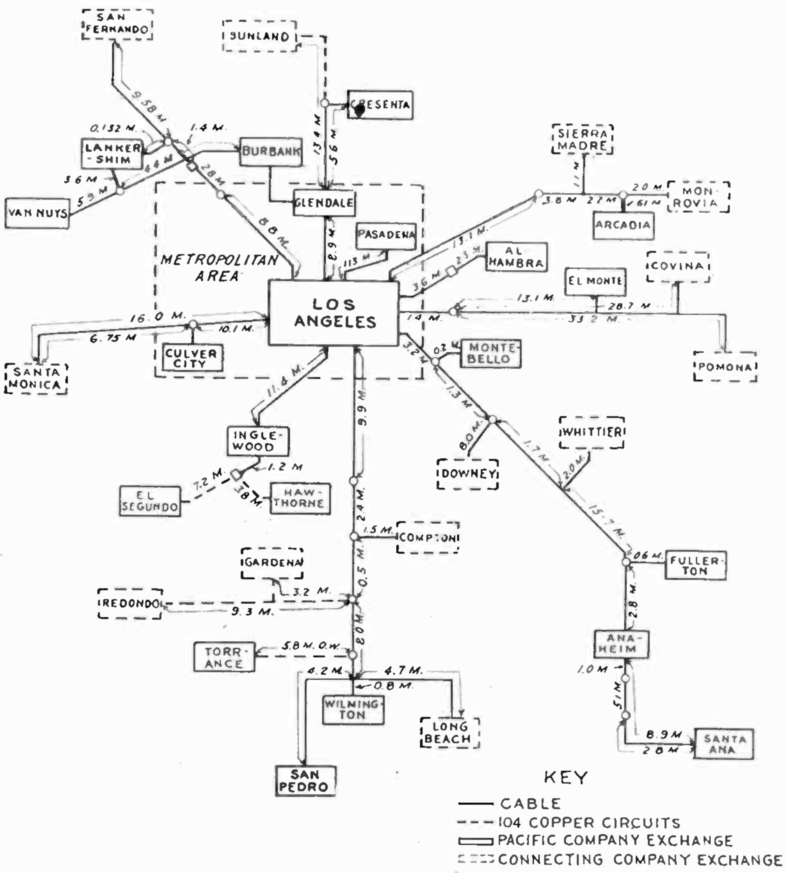

Fig. 4

equipment was installed in all manual offices in order that dial stations could complete calls to manual stations in the same manner as calls to dial stations. This equipment is known as call indicator equipment and employs decimal switches and a bank of numbered lamps to record and display before an operator the number of the desired station. The operating features that these manual service positions and call indicator equipment provided, materially aided in reaching the decision to adopt the dial tandem system.

The Los Angeles dial tandem system was gradually placed in service, starting March 30, 1926. It is designed to handle all of the short-haul toll traffic included within a maximum radius of approximately 40 mi. from the tandem center, except that which transmission and other considerations have prevented.

Fig. 4 indicates the routes and miles of cable and open-wire circuits between exchanges.

In June, 1927, the system was expanded to handle number service between exchanges within the metropolitan area, and in addition, to handle about 95 per cent of the number service between exchanges in the outlying area.

Under present conditions, the longest through connection practicable to establish over the tandem system is 55.7 mi. from office to office.

Description of the Tandem System

In general, the tandem system provides for a number of tandem trunks from the various offices in the tandem area terminating on first selectors of the step-by-step type located at the tandem center. Each level of the first selectors is wired to a group of second selectors on which are terminated completing trunks to the various offices served by the system. It will be noted that the use of first and second selectors will theoretically permit

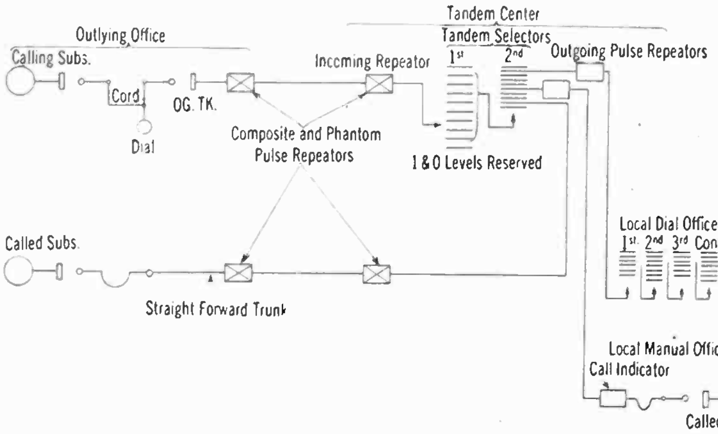

Fig. 5—Equipment Arrangement, Schematic Diagram

of reaching 100 different points, although practically this is somewhat limited because the first and zero levels of the first selectors are reserved for testing and special calls. As the system grows, third selectors can be introduced which will provide sufficient codes to care for the ultimate requirements. Two groups of first and second selectors are provided, one to handle calls from the outlying points to subscribers in Los Angeles, the other for calls from Los Angeles to subscribers in the outlying offices.

A subscriber in an outlying office desiring a Los Angeles number, see Fig. 5, will pass to his local operator the desired number as listed in the Los Angeles city directory. The local operator will then select an idle trunk to the tandem center and dial the number. If the call is to a dial system office, the first and second selectors at the tandem point will respond to the first two digits pulled by the operator to select the desired office. The remaining four or five digits, as the case may be, will be repeated on through the selectors and connectors at the terminating office to reach the proper called subscriber's line. If the called station is busy, a busy signal will be given to the originating operator. If the station is idle, the subscriber's bell will be rung automatically and upon the answer of the called party the supervisory cord lamp at the originating position will be extinguished as an indication to her that the called station has answered. The operation of the supervisory lamp by the called subscriber's switch hook provides the originating operator with complete supervision and a visual means for timing the call. After the completion of conversation, the calling and called parties will restore the receivers to the hooks, thereby causing the supervisory lamps on both cords to be lighted. The originating operator will then complete the timing, remove the answering cord from the subscriber's jack and the calling cord from the trunk to the tandem system which will cause the automatic release of all switches involved in setting up the connection. If the call is to a manual office, see Fig. 5, the connection will be established exactly the same way code to select a trunk to the desired outlying office. As soon as the trunk is seized, a signal will be displayed on the trunk before an incoming position. The incoming operator at the outlying office, upon answering the call, will automatically place a momentary tone on the connection which will indicate to the first operator that the incoming operator is ready to receive the desired number. The incoming operator, upon receiving the number, will complete the call to the desired subscriber by selecting the proper line jack in the manual switchboard multiple. As in the description of previous calls, the local operator in this case will also have complete supervision over both the calling and called subscribers.

The equipment required at an outlying office to provide the above described operating features consists in providing a sufficient number of tandem and com-

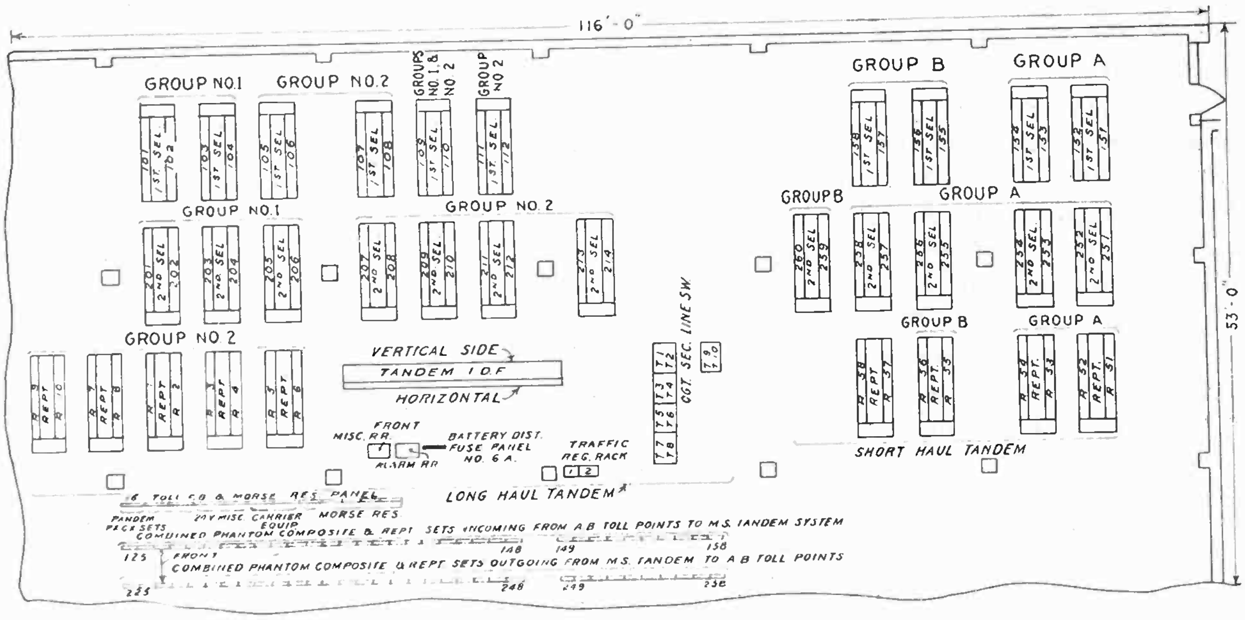

Fig. 9

except that the desired number will be displayed on one of the call indicator positions in the terminating manual office. The call indicator operator will complete the call in the same manner as she would a local call. The supervision obtained by the originating operator is the same as that described above for a call to a dial system subscriber. On calls from a manual office in Los Angeles to one of the outlying points, the functions performed by the subscriber and the local operator will be generally the same as that described above. On calls from a Los Angeles dial system office to an outlying office, the subscriber will first dial zero to reach his local operator after which the call will proceed in the same manner as described above for a call originating in a manual office. If the outlying point is a dial system office, the call will be completed in the same manner as described for a call from an outlying office to a dial system office in Los Angeles. If the call is for a manual outlying office, however, it will be completed by a straightforward operation; that is, the operator in Los Angeles will first dial the proper pleting trunks with their associated terminal equipment to handle the peak load of the traffic. The operator's cord circuits are modified so that her position dial can be associated with any cord; or in cases where the volume of traffic is relatively small, a cheaper arrangement, consisting of the provision of a dial cord, would be installed. It would be well to mention here that no equipment of this nature was required for the Los Angeles manual offices. These switchboards had already been modified for dialing and for call indicator operation in order to provide a suitable method for completing calls to and from dial system offices in the local metropolitan exchange area. If these modifications had not been made, the economies of the machine switching in preference to manual straightforward tandem operation might be questionable.

The floor plan layout of the tandem equipment at Los Angeles is shown in Fig. 9. On the left-hand side are the first and second selectors, pulse repeaters, distributing frame and outgoing secondary switches for completing calls to and from the more distant points; on the right-hand side the first and second selectors and pulse repeaters for completing calls to and from the nearby points are served by the tandem system. The first group, as noted on the sketch, is designated for convenience as the long-haul system and the second group as the short-haul system. These terms are merely equipment group designations and it should not be inferred that the two groups are provided for handling two types of traffic. A total of 2500 trunks terminates at the tandem office and 4000 selectors are required to do the switching.

The group of switches designated short-haul system performs the same functions as the group designated long-haul system except that it provides for the completion of calls to and from certain of the neighboring points to Los Angeles. The purpose of providing the so-called short-haul group is to permit of the use of small gage conductors on trunks which carry a relatively high volume of traffic between Los Angeles and outlying offices within approximately a 10-mi. radius. As an illustration of the economy of this arrangement, it would be necessary, if all calls to Pasadena were completed through a single group of tandem switches, to provide approximately 150—16-gage conductors in order that calls from Santa Ana, for example, would receive satisfactory transmission, although such calls are relatively few as compared with the total volume of traffic to Pasadena. By providing a separate group of selectors, known as the short-haul system, 20 conductors of 16 gage would be required on the long-haul system, whereas the remaining 130 trunks to Pasadena from the selectors of the short-haul system are of 19 gage and entirely satisfactory for the transmission requirements of the calls which it handles. The annual charges on 16-gage conductors per mile are approximately two times those for 19-gage.

A description of the selectors employed in the tandem system at Los Angeles is not required as they are of the well-known standard step-by-step type and are wired together in accordance with standard practises except that a cross-connecting frame is provided between selectors in order that the system will lend itself readily to expansion or other necessary rearrangement which may be brought about by future changes in traffic conditions.

The power for operating the various selectors, pulse repeaters and out-trunk secondary switches is obtained from the power plant of a standard step-by-step dial system central office located in the same building as the tandem equipment. At a number of the outlying offices it was necessary to add cells to the battery in order to raise the voltage to 48, which is required for the proper operation of the circuits.

The pulse repeaters which are used on both the incoming and outgoing trunks from the tandem and outlying offices to repeat dial impulses from one section of the circuit to another are new both with respect to circuits and to the association of various pieces of apparatus required in circuits. The relays of the pulse repeater are mounted on a removable base and covered as a protection against dust in the same manner as standard equipment. The associated composite and repeating coils are shown mounted directly above the repeater relay equipment. It is the usual practise in engineering toll telephone equipment to mount the composite and repeating coils together with their associated condensers on separate frames and wire this apparatus to test jacks on the toll testboard. Such an arrangement will provide a rapid means for replacing defective apparatus which may have rendered an expensive toll line inoperative. It was decided in the engineering of this installation to forego some of this flexibility since the toll lines involved did not exceed approximately 40 mi. It was, therefore, practical to associate the composite and repeating coils on the same frames as the relays, an arrangement which effects considerable economy in floor space, mounting racks and cabling, and also facilitates maintenance. The results of the operation of the tandem system with respect to maintenance, apparently justify our engineering decision in this respect.

In cases where large groups of trunks were required to handle traffic, such as between Long Beach and Los Angeles, considerable economy was effected by the use of outgoing trunk secondary switches. These switches perform the same function as the standard primary and secondary line switch arrangement employed in step-by-step dial system offices, the theory of which has been described in previous papers. Of course, in the case of the tandem system, the economies are somewhat more marked, due to the fact that the trunks involved are considerably more expensive than the trunks which are saved by the use of secondary line switches in local step-by-step office practises.

Where phantom trunks are not used, the pulse repeaters are the same as those employed between local Los Angeles offices.

Referring now to the operating features of the principal circuits involved in completing a call through the tandem system, see Fig. 11 which illustrates a typical circuit at an outlying manual office used in a call to a Los Angeles dial system subscriber. Particular attention will be given to a description of the novel dialing and signaling arrangement for phantom trunks and to the pulse correcting device of the incoming pulse repeater circuit.

When a calling subscriber in an outlying office lifts his receiver to originate a call, a circuit is closed from battery through the line relay on the contacts of the station switchhook. The resultant operation of the line relay closes a circuit to light the line lamp appearing before the operator who answers the call by inserting a plug of an answering cord into the subscriber's jack associated with the lighted line lamp. This closes a circuit by way of the sleeve of the answering cord to the cutoff relay in the line circuit, causing it to operate and disconnect the line relay from the subscriber's line, opening the lamp circuit, and extinguishing the line lamp. Battery is fed from the cord circuit repeating coil to the subscriber's set to energize his transmitter, and the calling supervisory lamp is under the control of the station switchhook.

The operator then obtains the desired number from the calling subscriber and if the number is in a local dial system office in Los Angeles she will select an idle trunk to the Los Angeles tandem office and insert therein the other end of the cord which she has used to answer the calling subscriber. Plugging into the outgoing trunk jack closes the circuit of the sleeve relay in the trunk to battery on the sleeve of the calling cord. The resultant operation of the sleeve relay, designated *S L* on the sketch, closes a circuit from ground through the winding of the *S* relay to battery on the ring conductor of the trunk. Relay *S* operates and locks on its own front contact, closing a circuit to operate the *P* relay and apply battery to the midpoint of the differential winding of the *C X* relay. Relay *S* also applies battery to the winding of the *A* relay which does not operate at this time.

The operator in dialing pulls the dial off normal, closing its off-normal contacts and operating the dial relay to associate the dial with the calling cord. The operation of this relay disconnects the repeating coil from that end of the cord and connects ground through the pulsing contacts of the dial to the tip conductor and ground through the off-normal contacts to the ring conductor of the cord. This latter application provides an operating ground for the *A* relay in the trunk, whose principal function is to connect the *P* relay to the tip conductor so as to prepare it to receive the pulses from the dial. The *P* relay repeats the pulses to a relay, corresponding to the *C X* relay of the trunk, in the incoming repeater at the tandem center, at the same time not affecting the *C X* relay in the trunk, which is used to receive a signal upon the answer of the called party and so extinguish the lighted supervisory lamp in the calling cord.

This two-way signaling feature, *i. e.*, pulsing in one direction and supervising in the other, over a single wire, is accomplished by an application to telephone signaling circuits of the familiar duplex principle of telegraphy. This application makes possible the use of phantomed trunks from the outlying points to the tandem center with accompanying economies in outside plant.

These trunks, as shown in Fig. 12, are provided with phantom coils and simplified composite sets, through which the four metallic leads of the phantom group are brought out to duplex relays. All of this apparatus is interposed on these trunks between the regular outdialing trunks, already described, and the incoming pulse repeaters at the tandem center.

Referring to the diagram, the action of an out-trunk circuit when picked up by an operator is to furnish battery instead of ground to the lead designated *S* on the particular channel selected. The resultant battery flow passes to the midpoint of the differential winding of the duplex relay and there divides in equal parts, one part passing by way of one-half of the differential winding over the line to the distant relay at the tandem center and the other part passing through the other winding and through an artificial network of electrical characteristics similar to the line attached to the other winding. These two current flows, being equal in strength, produce equal magnetomotive forces opposite in direction which have no effect upon the relay. That part of the current, however, which has passed over the line flows through the two windings of the distant duplex relay to ground through its associated artificial line and through the two windings of the relay in an aiding direction, operating this relay to actuate the repeater circuit and so pick up an incoming selector. Pulses from the operator's dial, therefore, will control this distant duplex relay, which in turn sets up the connection through the tandem system in the usual way.

On the answer of the called party, the incoming pulse repeater furnishes battery instead of ground to the lead designated *S*, which flows in opposite directions through the duplex relay windings, one part through the artificial line and the other over the line, through the two windings of the duplex relay at the outlying point. The operation of this relay retires the operator's supervisory lamp in the calling cord, indicating to her that the called party has answered.

At the completion of conversation, the hang-up of the

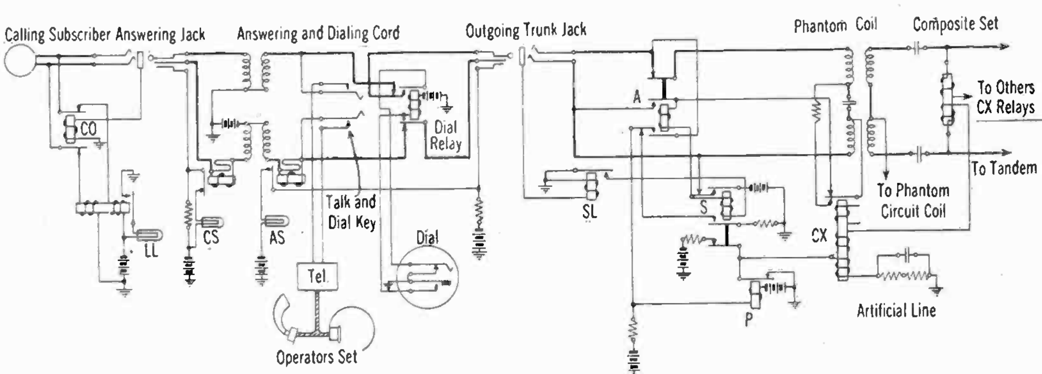

FIG. 11—OUTLYING OFFICE SIMPLIFIED CIRCUITS

called station causes the incoming selector to remove battery from the duplex circuit, releasing the $C X$ relay which lights the supervisory lamp associated with the calling cord as a disconnect signal. The disconnect of the operator removes the battery from the lead S, thereby releasing the distant duplex relay, which in turn releases the switch train.

A similar operation takes place when the phantom channel, designated "Trunk 2," in Fig. 12, is selected by an operator. The signaling, however, is done over the second wire of the first metallic pair. For the other side circuit, designated "Trunk 3," the signaling is done over one of the wires of the other metallic pair. This, it will be observed, utilizes but three wires of the four in the phantom group, allowing the use of the fourth to overcome any effect on the signaling relays which might be occasioned by current flow due to adverse ground potentials. This is accomplished by adding to each of the duplex relays a third winding, all connected in series by means of the fourth lead. Any ground potential difference between the two ends of the circuit which might cause current to flow through the differential windings of the duplex relays will be neutralized in effect by a similar current flowing through the compensating windings over the fourth wire.

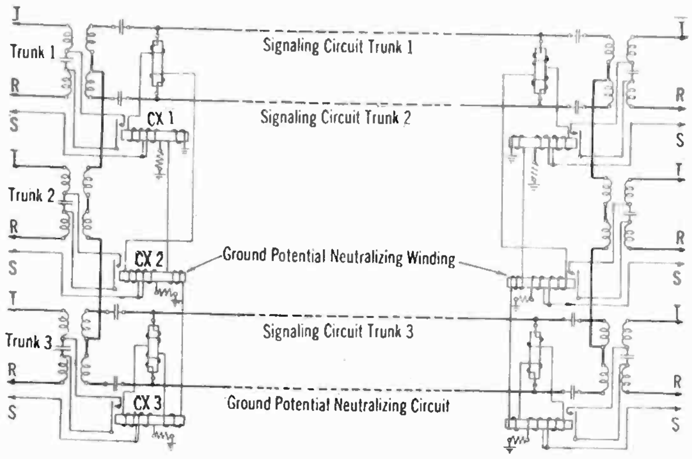

FIG. 12—PHANTOM TRUNK GROUP

Composite sets and phantom coils. Relays compensated for ground potential difference, simplified circuit.

The incoming pulse repeaters into which the duplex-composite circuits work have embodied in them a means for correcting for the distortion of dial pulses due to line characteristics. The use of this feature in the incoming repeaters makes it feasible to provide reliable service over longer trunks than has heretofore been practicable and so embrace in the system as many towns within the wide range of the tandem area as are economically warranted.

When the trunk is selected by an operator at an outlying point, the $C X$ relay of the incoming repeater at the tandem center shown in Fig. 13 is energized, as has been explained. This relay operates the A relay of the incoming repeater directly on its front contact, closing a circuit to operate a "slow operate" relay C and a "slow release" relay B in series. The latter relay closes a circuit to operate the K relay which locks, operated on its own front contact through a back contact of the J relay. The K relay also closes a circuit to operate the H relay which opens the original operating circuit of the K relay and closes on the contacts designated P, a bridge across the inside terminals of the repeating coil consisting of resistance F and relay E in series.

Current from the first selector of the tandem train flows through this bridge operating the A relay of the first selector in the usual way. Relay E is not affected by this current flow since it is polarized to operate on a current in the reverse direction.

At the first pulse from the operator's dial at the outlying point, the circuit operating the $C X$ relay is opened, causing the release of that relay. The A relay in turn is released, opening the circuit through the C and B relays. The former releases, and being slow to operate, remains released during the train of pulses following, while the latter, being slow to release, remains operated during this time. On its other back contact, the relay A grounds the condenser A through the resistance B.

On the opening of the circuit at the first pulse, nothing occurs in the repeater to affect the condition of the associated first selector. On the closure of the circuit at the end of the first pulse, a pulse of measured length is sent to operate the first selector as follows:

The operation of the $C X$ relay closes the circuit to the A relay which connects the discharged condenser A to battery through the winding of relay J. On the short surge of charging current the relay J momentarily operates, opening the locking circuit of the K relay, causing it to release, and open the contacts designated P to start the first pulse to the selector. The release of the K relay also opens the circuit to the winding of the H relay which, when released, establishes the original operating circuit of the K relay, which operates to close the P contacts completing the pulse and to lock through the now restored back contact of the J relay.

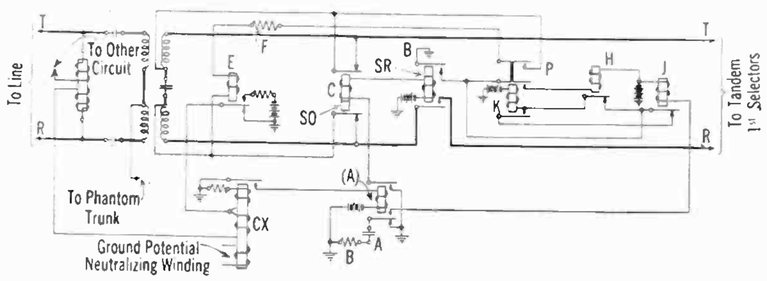

FIG. 13—INCOMING PULSE REPEATER

With pulse corrector simplified circuit

The length of the pulse to the first selector is determined by the release and operate time of the H and K relays, respectively, thus correcting for any distortion of dial pulses due to line characteristic.

Succeeding pulses of the first digit and following digits are repeated in like manner to the selectors of the tandem train of switches, and through an outgoing trunk repeater to the switch train of the local office, to select in the manner well known in step-by-step practise, the terminal of the called line.

Upon the answer of the called subscriber, the battery flow from the tandem switch train to the incoming repeater is reversed, operating the polarized relay E. The midpoint of the differential winding of the $C\,X$ relay is thereby changed from ground to battery, causing, as previously outlined, the operation of the $C\,X$ relay in the outgoing trunk at the outlying office and the subsequent extinguishing of the calling supervisory lamp.

At the completion of conversation the current flow through the E relay again reverses, causing the release of the relay and lighting of the distant supervisory lamp as a disconnect signal. The disconnection by the operator releases the $C\,X$ and A relays, opening the circuit to release the B and K relays. The opening of contact P of the K relay restores the switches of the tandem train.

Where the trunks outgoing from the tandem office terminate in local manual offices equipped with call indicator completing positions, a pulse repeater is

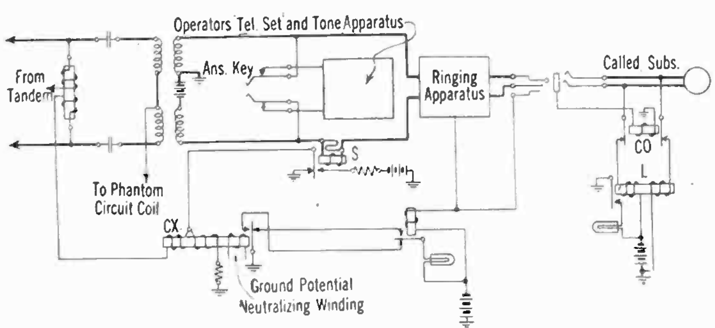

Fig. 14—Complete Trunk, Simplified Circuit

provided to repeat the decimal pulses directly to the call indicator display apparatus. This apparatus is substantially the same as that in use in panel dial system offices which has been described in early papers on the panel system.[3]

Trunks outgoing to manual offices not equipped with call indicator are operated by what is known as the straightforward trunking method. This method embraces most of the offices in the outlying towns which connect to the tandem system, and a simplified diagram of one of the types of trunk circuits is shown on Fig. 14.

When the trunk is selected at the tandem point, the outgoing repeater sends battery over one of the wires of the phantom trunk group, in a manner similar to that already described for the outgoing trunks, to cause the relay $C\,X$ to operate, lighting the guard lamp through a chain of relays to appraise the operator of a waiting incoming call. The operator answers by operating the talking key on the completing trunk, bringing into play apparatus in her telephone circuit which sends a momentary tone to the calling operator, to advise her that the completing operator is ready to receive the call. She then plugs the completing cord into the multiple jack of the line desired.

The sleeve circuits of the cord and line are closed, operating the cut-off relay in the line to remove the associated line relay and setting in operation the machine ringing apparatus in the cord.

When the called subscriber answers, machine ringing is tripped and the circuit closed through to the repeating coil in the cord. Battery through the repeating coil flows over the line to energize the station transmitter and operates the series supervisory relay S. This relay in operating places battery on the midpoint of the differential winding of the $C\,X$ relay, causing the $C\,X$ relay in the outgoing repeater to operate, and by means of a reversing relay, reverse the battery flow through the tandem switch train to the incoming repeater. As already described, this results in retiring the calling supervisory lamp at the originating office.

At the completion of conversation the hang-up of the calling party lights the calling supervisory lamp as a disconnect signal and the called party's hang-up lights the other supervisory lamp. The disconnect of the originating operator releases the tandem switch train, in turn releasing the outgoing trunk and lighting the disconnect lamp through the back contact of the now restored $C\,X$ relay at the completing position.

Placing the Tandem System in Operation

With the introduction of the dial tandem service came many interesting problems. As in most cases where communities are joined together by new communication methods, the various interests and general viewpoints of those concerned present an interesting and difficult problem to solve on a mutually satisfactory and equitable basis. The area includes 12 connecting companies which were using five different makes of equipment. The two larger of these included one exchange of 28,000 stations and another of more than 13,000 stations, both of which originated a large amount of toll traffic in proportion to their size. In addition to providing new equipment and rearranging existing equipment at the outlying points, it was necessary to instruct the local operating force at each place in the proper operation and maintenance of their equipment in order to obtain the desired service results.

In order to acquaint the operators with the tandem system, a number of bulletin cards with the names and codes of offices was prepared and placed on each position handling tandem calls. Information and instructions as to whether the tandem code together with the subscriber's number or only the code should be dialed in passing the order to the completing operator, also were included. Very little educational work was required in the training of the operators in Los Angeles as they were already accustomed to dialing. The straightforward completing feature of the tandem system was

3. Paper by Craft, Morehouse and Charlesworth, A. I. E. E. Trans., Vol. XLII, 1923, p. 187.

quite like the manual straightforward tandem system already in operation. Considerable training was done in the outlying offices, however, as many of the operators were not accustomed to dialing and in some cases were not familiar with the requirements in the proper handling of short-haul toll traffic. A brief description of the tandem method of operation was prepared for each outlying town, which was discussed with the supervisory officials who presented the problem to their forces. The questions and answers presented in these conferences resulted in a knowledge of the system as well as the details of the operators' work being known to the operating forces before service was started. In establishing the many routes which were made effective with the opening of the tandem system, it was essential that means be provided so that customers might easily obtain telephone numbers in other exchanges and the necessary routines were established to accomplish this.

A series of tests of equipment was made at the outlying offices where limits were severe. These tests included dialing and signaling from minimum to maximum limits with respect to line leakage and line balance resistance, relay adjustments, and voltage variation. The amount of cross-talk and audible interference from dialing and signaling was determined. On open-wire routes, particular attention was directed to line leakage and balance of composite sets located at the cable junction. When placed in service, each cut-over operation was limited to trunks in one direction only and, as far as possible, but one office was brought in at a time. Thus, the change from the toll board to the dial tandem method was carried out in an orderly manner with the least possible confusion to and reaction on service. In some cases, a few trunks only were placed in operating condition several days before actual service was established over the route in order to give the operators preliminary training during their regular work. Maintenance routines and practises were issued sufficiently in advance of the cut-over so that practically no difficulties were experienced in equipment failures. Very close cooperation was necessary between the equipment and traffic engineers and the cut-over field forces of the Traffic and Plant Maintenance Departments. The schedule of cuts was thoroughly coordinated and the people who were finally charged with the responsibility of operating and maintaining the system were well trained.

It was originally planned to cut-over all the offices involved during May, 1926, and in addition, to introduce number service to other points within a 40-mi. radius of Los Angeles. With the completion of the installation at the tandem office in March, it was found possible to start service earlier to most of the offices handling a comparatively large volume of the traffic. A sequence cut, therefore, was planned which would permit the tandem system to carry the traffic gradually, avoiding any too abrupt change in operation or labor requirements in the various offices. The actual cut-over of the initial equipment comprised a period of nearly two months. Following this, other exchanges have been given the service from time to time, temporary equipment being replaced with permanent, so that there now remain only six points originally planned for the tandem system that are not actually receiving its full benefit. These exchanges are Arcadia, Covina, Pomona, Redondo, Sunland, and Torrance. The most recent cut-over of magnitude in this connection was in June, 1927, when Pasadena was changed from manual to dial operation. At this time a tandem center was established serving Pasadena exchange with direct connections to four Los Angeles offices and to the following outlying exchanges: Alhambra, Arcadia, Crescenta, Glendale, Monrovia and Sierra Madre.

SOUTHEAST ENGLAND ELECTRICITY SCHEME

The southeast England electricity scheme, 1927, prepared by the electricity commissioners, is now in the hands of the central electricity board, the official superpower company, which is to generate electricity and distribute it wholesale throughout Great Britain. The board will consider any changes which interested parties may wish to suggest and will then take the necessary steps to make the scheme a reality. This is the second program of the sort prepared by the electricity commissioners: the first one, having to do with Scotland, was simpler, as it was only involved in the two industrial districts of Glasgow and Edinburgh.

The growth of output in Great Britain for the four years up to and including 1924-25 disclosed an increase of approximately 11.5 per cent a year in the total number of kilowatt-hours sold by central light and power stations. A detailed examination of the official statistics for each of the stations in the area resulted in adopting a higher average rate of increase of 16.9 per cent a year on the recorded output for 1925-26 for the first eight years. The kilowatt-hours sold to consumers within the area of the scheme amounted to 1,282,000,000 in 1925-26, and on the assumed rate of growth will reach a total of 3,019,000,000 in 1933-34, equivalent to 265 kilowatt-hours per person of population at the last census, the estimated maximum simultaneous demand on the generating stations operated for the central board being 1,424,000 kilowatts.

The commissioners have adopted for the southeast England area an average rate of increase of 20.4 per cent for the years between 1933-34 and 1940-41. It is estimated that the kilowatt-hours sold to consumers in 1940-41 will reach a total of 4,855,000,000, equivalent to 426 kilowatt-hours per person, and that the maximum simultaneous demand on the generating stations operated for the central board will be 2,191,000 kilowatts.

The area under consideration in this scheme is about 8828 square miles in extent.—*Commerce Reports.*

Abridgment of

Static Stability Limits and the Intermediate Condenser Station

BY C. F. WAGNER* Associate, A. I. E. E. and R. D. EVANS* Member, A. I. E. E.

THE development in power transmission has been in the direction of delivering increased amounts of power per circuit over greater distances. This trend raises two fundamentally important questions:

1. What constitute the output limitations of the alternating current system of power transmission, and
2. How close to these limits is it feasible to operate transmission systems?

During the past few years, investigations have been under way to find the answers to these questions. Stability has been recognized as the outstanding output limitation of power systems utilizing synchronous machines of the types now in use. There have been a number of proposals for increasing the stability limits of power systems. The use of lower system frequency and the reduction of the series impedance of the system are obviously of value in increasing the stability limits. Recently, the latter method, by decreasing the machine impedance, has been adopted in a number of transmission undertakings. Of course, raising the transmission voltage has been considered, but it is relatively expensive and does not avoid the "distance limitation" in lines approaching the quarter wave resonant length. This effect becomes important for distances considerably below the theoretical value because of the impedance of terminal equipment.

One proposal of greater promise than any of those mentioned in the previous paragraph is the use of the intermediate synchronous condenser station. In 1921 Mr. F. G. Baum presented an important paper devoting a considerable part of it to the use of intermediate condenser stations, which he advocated as a method of making technically feasible the transmission of 60-cycle power to substantially unlimited distances.

Since the early proposals to utilize the intermediate condenser station to increase the stability limits of transmission systems, the entire subject has received a very great deal of attention before the Institute and in the technical press. During 1924, Messrs. Evans and Bergvall presented the results of tests made during the previous year, giving experimental verification of the increases in stability limits possible by the intermediate condenser. The tests were made on a miniature power system and showed improvements as great as 42 per cent. In the bibliography is listed a number of technical papers published in America dealing with the intermediate condenser station problem.

It is desirable at the outset to point out the limitations of the investigations. The present paper is confined to static limits. Static limits are important because they may be approached under emergency conditions even though the system is designed to operate well below these limits normally. It is recognized that stability limits under transient conditions occur for smaller values of transmitted power. The authors presented a step-by-step method applicable for the determination of the transient limits of transmission systems including intermediate condensers. It may be pointed out that static limits are best investigated by the application of a criterion obtained on the basis of small transients.

General Representation of Systems

In general, the solution of any physical problem is reached by the solution of equations, the number of these equations being equal to the number of unknown quantities in the problem. This is also true for a-c. networks with fixed constants. Because of the linear nature of the first and second laws of Kirchhoff, which alone are necessary for a solution, the simultaneous equations are always linear, with constant coefficients. The solution for the terminal currents in terms of the terminal voltages of an n terminal network can always be reduced to the following form*

$$\left.\begin{aligned} \mathbf{I}_a &= \mathbf{Y}_{aa}\mathbf{E}_a - \mathbf{Y}_{ab}\mathbf{E}_b - \mathbf{Y}_{ac}\mathbf{E}_c \ldots\ldots - \mathbf{Y}_{an}\mathbf{E}_n \\ \mathbf{I}_b &= -\mathbf{Y}_{ba}\mathbf{E}_a + \mathbf{Y}_{bb}\mathbf{E}_b - \mathbf{Y}_{bc}\mathbf{E}_c \ldots\ldots - \mathbf{Y}_{bn}\mathbf{E}_n \\ \mathbf{I}_n &= -\mathbf{Y}_{na}\mathbf{E}_a - \mathbf{Y}_{nb}\mathbf{E}_b - \mathbf{Y}_{nc}\mathbf{E}_c \ldots\ldots + \mathbf{Y}_{nn}\mathbf{E}_n \end{aligned}\right\} \quad (1)$$

in which the coefficients $\mathbf{Y}_{aa}$, $\mathbf{Y}_{bb}$ . . . . $\mathbf{Y}_{nn}$ are termed self admittances, and the coefficients $\mathbf{Y}_{ab}$, $\mathbf{Y}_{mn}$, etc., are termed mutual admittances. It can be shown that $\mathbf{Y}_{mn}$ is equal to $\mathbf{Y}_{nm}$. The network is then completely defined so far as the terminal conditions are concerned by n self admittances and $\frac{n}{2}\ (n-1)$ mutual admittances. A two terminal network will reduce to a network of two self admittances and one mutual admittance, a three-terminal network will reduce to a network of three self admittances, and three mutual admittances. The physical significance of these notions may be illustrated by considering in more detail a three terminal network. The equations for this case are

*Both of Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Presented at the Pacific Coast Convention of the A. I. E. E., Del Monte, Calif., September 13-16, 1927. Complete copies upon request.

*Complex quantities will be designated in this paper by a bold face roman type. The conjugate will be designated by old English type. Italic type indicates absolute value.

$$\left.\begin{aligned} \mathbf{I}_a &= \mathbf{Y}_{aa}\,\mathbf{E}_a - \mathbf{Y}_{ab}\,\mathbf{E}_b - \mathbf{Y}_{ca}\,\mathbf{E}_c \\ \mathbf{I}_b &= -\,\mathbf{Y}_{ab}\,\mathbf{E}_a + \mathbf{Y}_{bb}\,\mathbf{E}_b - \mathbf{Y}_{bc}\,\mathbf{E}_c \\ \mathbf{I}_c &= -\,\mathbf{Y}_{ca}\,\mathbf{E}_a - \mathbf{Y}_{bc}\,\mathbf{E}_b + \mathbf{Y}_{cc}\,\mathbf{E}_c \end{aligned}\right\} \quad (2)$$

Now, referring to Fig. 3 it will be seen that the above equations represent the solution of the network indicated.

Discussion of the Assumptions Involved

The general method described in the previous section is the only one available for analytical calculation of stability limits of power system networks. Transformers, reactors and lines may be represented in the usual manner by general networks with constant impedance and admittance branches. The accuracy of the general method depends upon the justification of the following approximations:

1. Synchronous machines may be represented by a source of voltage and a series impedance.
2. Loads may be represented by shunt admittances alone or in combination with synchronous machines.

Two-Machine Problem

The problem involving two sources of synchronous a-c. voltages have been termed the "Two Machine Problem." The solution given here represents the general case for any two synchronous machines connected to networks in which the load can be represented by pure admittances or shaft loads on the synchronous machines. These machines may be operating as two generators, as one generator and one motor, or as one generator and a condenser. The current at the terminals of the machines can always be expressed in terms of the internal voltages by the following equations:

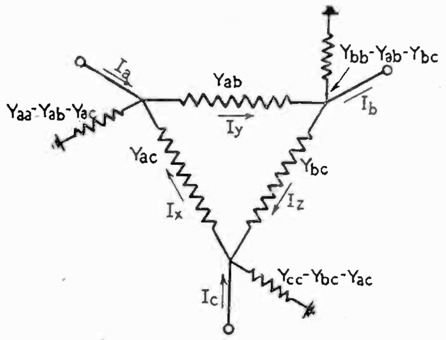

Fig. 3—Admittance Diagram Representing General Case for a Three-Terminal Network

$$\left.\begin{aligned} \mathbf{I}_a &= \mathbf{Y}_{aa}\,\mathbf{E}_a - \mathbf{Y}_{ab}\,\mathbf{E}_b \\ \mathbf{I}_b &= -\,\mathbf{Y}_{ab}\,\mathbf{E}_a + \mathbf{Y}_{bb}\,\mathbf{E}_b \end{aligned}\right\} \quad (9)$$

in which currents in the positive sense are taken as flowing *out* of the machine and *into* the network, $\mathbf{I}_a$ and $\mathbf{I}_b$ are line currents and $\mathbf{E}_a$ and $\mathbf{E}_b$ are star voltages which are considered as being secured rigidly to the rotor so that their time rates of change are determined by the time rates of change of their rotors.

The real and reactive components of power output of the two generators are:

$$\begin{aligned} P_a + j\,Q_a &= 3\,\mathbf{E}_a\,\mathfrak{I}_a \\ &= 3\,\mathfrak{Y}_{aa}\,E_a^2 - \mathfrak{E}\,\mathfrak{Y}_{ab}\,\mathbf{E}_a\,\mathfrak{E}_b \\ P_b + j\,Q_b &= 3\,\mathbf{E}_b\,\mathfrak{I}_b \\ &= -\,3\,\mathfrak{Y}_{ab}\,\mathfrak{E}_a\,\mathbf{E}_b + 3\,\mathfrak{Y}_{bb}\,E_b^2 \end{aligned}$$

or in terms of their line to line voltages:

$$\left.\begin{aligned} P_a + j\,Q_a &= \mathfrak{Y}_{aa}\,E_A^2 - \mathfrak{Y}_{ab}\,\mathbf{E}_A\,\mathfrak{E}_B \\ P_b + j\,Q_b &= -\,\mathfrak{Y}_{ab}\,\mathfrak{E}_A\,\mathbf{E}_B + \mathfrak{Y}_{bb}\,E_B^2 \end{aligned}\right\} \quad (10)$$

Let

$$\left.\begin{aligned} \mathbf{E}_A &= E_A\,\epsilon^{j\phi_A} \\ \mathbf{E}_B &= E_B\,\epsilon^{j\phi_B} \\ \mathbf{Y}_{ab} &= Y_{ab}\,\epsilon^{j\phi_1} \\ \mathbf{Y}_{aa} &= Y_{aa}\,\epsilon^{j\phi_7} \\ \mathbf{Y}_{bb} &= Y_{bb}\,\epsilon^{j\phi_8} \end{aligned}\right\} \quad (11)$$

then

$$\left.\begin{aligned} P_a + j\,Q_a &= Y_{aa}\,E_A^2\,\epsilon^{-j\phi_7} \\ &\quad - Y_{ab}\,E_A\,E_B\,\epsilon^{j(\phi_A - \phi_B - \phi_1)} \\ P_b + j\,Q_b &= -\,Y_{ab}\,E_A\,E_B\,\epsilon^{j(\phi_B - \phi_A - \phi_1)} \\ &\quad + Y_{bb}\,E_B^2\,\epsilon^{-j\phi_8} \end{aligned}\right\} \quad (12)$$

and since $\epsilon^{j\theta} = \cos\theta + j\sin\theta$

$$\left.\begin{aligned} P_a &= Y_{aa}\,E_A^2\cos\phi_7 \\ &\quad - Y_{ab}\,E_A\,E_B\cos(\phi_A - \phi_B - \phi_1) \\ P_b &= -\,Y_{ab}\,E_A\,E_B\cos(\phi_A - \phi_B + \phi_1) \\ &\quad + Y_{bb}\,E_B^2\cos\phi_8 \end{aligned}\right\} \quad (13)$$

These equations define the electrical output at a and at b. The mechanical input will be designated by P_{ga} and P_{gb} in which input as for a generator will be considered positive and input as for a motor having a shaft load as negative. The difference between the input and output of say a turbine-generator set is thus expressed by $P_{ga} - P_a$. This can be converted to acceleration of the rotor by means of equation (8), so that α_A or $\dfrac{d^2\,\phi_A}{d\,t^2}$, is equal to

$$\begin{aligned} \alpha_A &= \frac{d^2\,\phi_A}{d\,t^2} = \frac{180\,f}{W_a}\,(P_{ga} - P_a) \\ &= \frac{180\,f}{W_a}\,P_{ga} - \frac{180\,f}{W_a}\,Y_{aa}\,E_A^2\cos\phi_7 + \\ &\quad + \frac{180\,f}{W_a}\,Y_{ab}\,E_A\,E_B\cos(\phi_A - \phi_B - \phi_1) \end{aligned} \quad (14)$$

$$\begin{aligned} \alpha_B &= \frac{d^2\,\phi_B}{d\,t^2} = \frac{180\,f}{W_b}\,(P_{gb} - P_b) \\ &= \frac{180\,f}{W_b}\,P_{gb} - \frac{180\,f}{W_b}\,Y_{bb}\,E_B^2\cos\phi_8 \\ &\quad + \frac{180\,f}{W_b}\,Y_{ab}\,E_A\,E_B\cos(\phi_A - \phi_B + \phi_1) \end{aligned} \quad (15)$$

These expressions determine the rate of change in the absolute position of the voltage vectors. In the final analysis, however, it is the variation of the difference in angle between the two voltages, the phase angle difference, that is really important. So long as the phase difference between the two voltages does not exceed a certain value the actual changes in their position in space is unimportant.

Let

$$\phi_A - \phi_B = \phi \tag{16}$$

$$\frac{d^2\,\phi}{d\,t^2} = \frac{d^2\,\phi_A}{d\,t^2} - \frac{d^2\,\phi_B}{d\,t^2} = \alpha_A - \alpha_B = \alpha \tag{17}$$

From equations (**14**) and (**15**)

$$\alpha = 180\,f\left\{\frac{P_{ga}}{W_a} - \frac{P_{gb}}{W_b} + \frac{Y_{bb}\,E_B^2}{W_b}\cos\phi_3 - \frac{Y_{aa}\,E_A^2}{W_a}\cos\phi_1 + Y_{ab}\,E_A\,E_B\left[-\left(\frac{1}{W_a} - \frac{1}{W_b}\right)\cos\phi_1\cos\phi + \left(\frac{1}{W_a} + \frac{1}{W_b}\right)\sin\phi_1\sin\phi\right]\right\} \tag{18}$$

This equation completely determines the oscillation between the machines resulting from a disturbance for the given circuit conditions, voltages, inertias, and governor settings. Circuit conditions, inertia of machines, shaft loads of motors and prime mover inputs of generators can be assumed constant, the last named because of the relatively sluggish action of governors. The voltages appearing in the equations are machine voltages which are assumed constant in magnitude. The above equation can be solved by elliptic functions or by step-by-step methods. For small variations from the mean angle the following method may be used

$$\Delta\,\alpha = \frac{d\,\alpha}{d\,\phi}\,\Delta\,\phi$$

$$= 180\,f\,Y_{ab}\,E_a\,E_b\left[-\left(\frac{1}{W_a} - \frac{1}{W_b}\right)\cos\phi_1\sin\phi + \left(\frac{1}{W_a} + \frac{1}{W_b}\right)\sin\phi_1\cos\phi\right]\Delta\,\phi \tag{19}$$

It is interesting to note that only the mutual admittance enters this equation, the two self impedances disappearing because they are not associated with terms that vary with the angle.

In analyzing the conditions for stable operation at a given operating point several criteria suggest themselves. One of the rotors can be displaced forcibly from its position of equilibrium and the relations analyzed to determine whether it will return to its original position. An increment of load could be placed on the shaft of one unit and the conditions investigated for stable operation. Another disturbance suggests itself in decreasing the network load by changing the network constants. The latter two involve a change in frequency or governor setting to determine the final steady state operating conditions. For this reason the change in angular position constituting the disturbing factor will be selected.

The criterion for stability shall be that the system return to its original position after a slight displacement of the angle between the machines. Let ϕ_0 be the steady state angle and θ the departure of ϕ from this angle, then

$$\phi = \phi_0 + \theta \tag{20}$$

$\Delta\,\phi$ is then equal to θ for small value of θ and $\alpha = \frac{d^2\,\phi}{d\,t^2} = \frac{d^2\,\theta}{d\,t^2}$. Since the acceleration is zero for $\phi = \phi_0$, everything being balanced for this particular value, then $\Delta\,\alpha = \alpha$ for small values of α.

Equation (**19**) may now be written

$$\frac{d^2\,\theta}{d\,t^2} = 180\,f\,Y_{ab}\,E_a\,E_b\left[-\left(\frac{1}{W_a} - \frac{1}{W_b}\right)\cos\phi_1\sin\phi_0 \quad \left(\frac{1}{W_a} + \frac{1}{W_b}\right)\sin\phi_1\cos\phi_0\right].\,\theta \tag{21}$$

This has the same form as the simple differential equation

$$\frac{d^2\,\theta}{d\,t^2} = K\,\theta \tag{22}$$

which is the equation for simple harmonic motion so long as K is negative. The condition then that the motion resulting from a disturbance be oscillatory and not continue with increasing angle and finally pull out is that the coefficient of θ be negative; then for any small displacement θ the rotors will always return to their original relative position. Since the quantity $180\,f\,Y_{ab}\,E_a\,E_b$ is positive the condition for stable operation reduces to the relation that

$$\left(\frac{1}{W_a} + \frac{1}{W_b}\right)\sin\phi_1\cos\phi_0 - \left(\frac{1}{W_a} - \frac{1}{W_b}\right)\cos\phi_1\sin\phi_0 < 0 \tag{23}$$

The limiting condition is reached for that value of ϕ_0 for which

$$\left(\frac{1}{W_a} + \frac{1}{W_b}\right)\sin\phi_1\cos\phi_0 - \left(\frac{1}{W_a} - \frac{1}{W_b}\right)\cos\phi_1\sin\phi_0 = 0$$

or for

$$\tan\phi_0 = \frac{W_b + W_a}{W_b - W_a}\tan\phi_1 \tag{24}$$

It can be seen from this that the limiting angle is a function of the inertia of the two machines and of the argument of the complex number representing the mutual admittance Y_{ab}. This result is contrary to the previously accepted theory which neglected the influence of the relative values of the inertia.

For

$$W_a = \infty$$

$$\tan \phi_0 = - \tan \phi_1$$

$$\phi_0 = - \phi_1 + n\,\pi$$

where n is any integral number.

For $W_b = \infty$

$$\phi_0 = \phi_1 + m\,\pi$$

For $W_a = W_b$

$$\phi_0 = \pi / 2 \tag{25}$$

For those cases usually met in practise in which a is the sending end and b the receiving end of a transmission system

$$n = 0 \text{ and } m = 1, \text{ so that}$$

for

$$W_a = \infty, \phi_0 = - \phi_1 \tag{26}$$

and for

$$W_b = \infty, \phi_0 = \pi + \phi_1 \tag{27}$$

These general considerations perhaps, may, be seen more clearly by analyzing the expressions for α_a and α_b in the light of the power circle diagrams. Consider machine a as a generator and machine b as a motor connected by a simple impedance $\mathbf{Z}$. The motor shall be loaded by a shaft load of essentially constant power. (see Fig. 8). The coefficients for this case will then be:

$$\mathbf{Y}_{aa} = \mathbf{Y}_{ab} = \mathbf{Y}_{bb} = \frac{1}{R + j\,X} = \frac{1}{Z\,\epsilon^{j\psi}} = \frac{1}{Z}\,\epsilon^{-j\psi}$$

so that equations (12) become

$$P_a + j\,Q_a = \frac{1}{Z}\,E_A{}^2\,\epsilon^{j\psi} - \frac{1}{Z}\,E_A\,E_B\,\epsilon^{j(\phi + \psi)} \tag{28}$$

$$P_b + j\,Q_b = - \frac{1}{Z}\,E_A\,E_B\,\epsilon^{j(-\phi + \psi)} + \frac{1}{Z}\,E_B{}^2\,\epsilon^{j\psi} \tag{29}$$

Reversing the positive reference of current flow at B

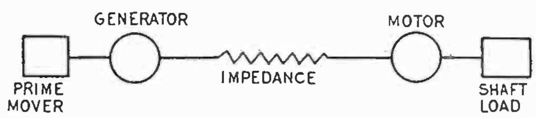

Fig. 8—Simple Power System

to correspond to the more usual practise the power expression for B becomes:

$$P_{b1} + j\,Q_{b1} = + \frac{1}{Z}\,E_A\,E_B\,\epsilon^{j(-\phi + \psi)} - \frac{1}{Z}\,E_B{}^2\,\epsilon^{j\psi} \tag{30}$$

Equations (28) and (29) can be plotted in the usual form of power circle diagrams shown in Fig. 9. The point a, being the center of the sending-end circle, is determined by the first term in equation (28); the second term may be drawn with a as center and radius equal to the absolute value of the second term. For $\phi = 0$ the line will lie along $o\,a$. This line constitutes the reference line. For other values of ϕ the particular angle is

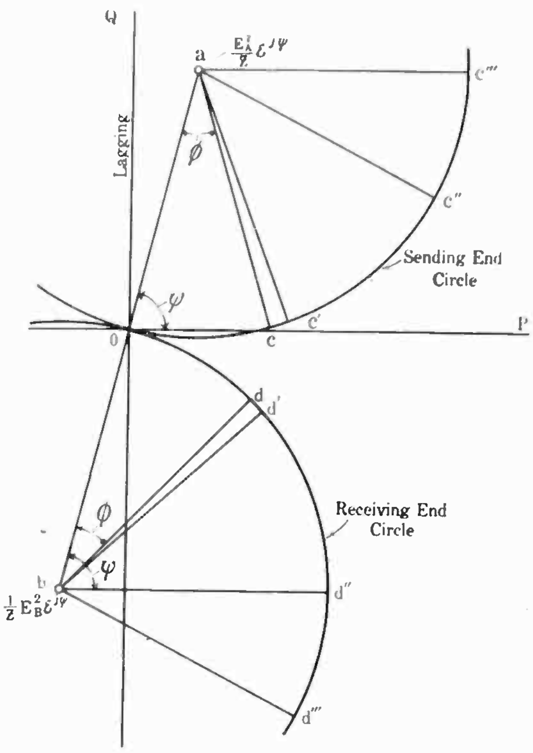

Fig. 9—Power Circle Diagram for the Simple Power System Shown in Fig. 8

measured from this line, positive angles rotating the vector counter-clockwise. The receiver circle is plotted in a similar manner with center at b determined by the last term of equation (30). Positive angles are measured in clockwise rotation from $b\,o$. Now suppose the systems were operating at the point c on the sending end circle which corresponds to d on the receiving circle. The governor would be set for the power corresponding to c and the power, or torque since speed changes so slightly, on the motor would correspond to point d. Any slight instantaneous change in the operating angle would change the operating points to c' and d'. Since the governor setting and motor torque are constant the increased power output at the generator end tends to slow up the rotor of the generator and speed up the rotor of the motor and thus reestablish the original operating angle. This is an inherently stable operating position. The acceleration at either end varies directly as the excess of output over input and inversely as the inertia of the rotor. The actual rate of change, the resultant acceleration, of the angle is a resultant of the effects at the two ends. Both effects act in the same direction up to the angle corresponding to maximum power at the receiver, (point of vertical tangency), *i. e.*, up to this point a small increment in angle produces retardation of the rotor at the generator or sending end and *acceleration* of the rotor of the motor but both effects tend to *decrease* the angle and to this extent act in the same direction. Slightly beyond this point an increment in angle produces retardation of the rotor at the receiving end. Both ends are now retardation. The resultant effect on the system depends upon which of the two retardations is the greater and these in turn are dependent upon the relative inertias of the two machines. For equal inertias and angles less than $\pi/2$, the generator will retard faster than the motor for positive increments in angle. When the angle is $\pi/2$ the retardation are equal but within the range of line angle, ψ to $\pi/2$, while both ends retard the generator retards sufficiently rapidly to maintain synchronism. The system as a whole will retard, reducing the frequency, but this will be taken care of by the automatic governors.

When the inertia of the generator is infinite the acceleration of the generator for any finite change in power is zero, so that the acceleration or retardation of the angle is determined entirely by that of the motor rotor. For positive increments in angle the acceleration of the motor rotor is positive up to the point where the line angle reaches ψ, beyond which it becomes negative. The stability of the system for this condition is coincident with the condition of maximum power at the receiver (d'' in Fig. 9) and the line angle is ψ, the argument of the complex number representing the admittance $\mathbf{Y}_{ab}$. When the inertia of the motor rotor is infinite the limit is determined for similar reasons by the condition of maximum power at the generator. This corresponds to a line angle of $\pi - \psi$, the operating points of which are indicated by c''' and d''' in Fig. 9. It is interesting to note in this connection that it is not only possible theoretically to operate beyond the point of maximum power of the receiving circle diagram such as discussed for conditions when the inertia of the rotor of generator is other than infinite, but it is possible to operate beyond an angle of $\pi/2$, when the inertia at the receiving end is greater than that at the generator. While this is the condition usually met in practise it is not being advocated here to operate a system within that zone.

It follows from the above discussion that while the point of maximum power might be a stable operating point this method might give a result which would indicate that for the maximum angle at which it is possible to operate, the stability limit is lower than the maximum power, (*i. e.*, that the power at say d''' is lower that at d''). But to arrive at this operating point it is necessary with slowly increasing load to pass through the point of maximum power of the circle diagram. In such case the system reaches a maximum power limit before a stability limit. These ideas are merely being developed here to insure a clearer conception of static stability. Some of these operating conditions which are here shown to be stable were heretofore considered inherently unstable.

Practical Calculation of Static Stability

The most general case in which the problem can be reduced to a single synchronous machine at each end is worked out in the unabridged paper together with an illustrative example.

Stability Limit of 220- and 110-Kv. Transmission Systems

The methods which have just been described have been applied to the calculation of the stability limits of 60-cycle, 220-kv. transmission systems of various lengths. Fig. 15 shows the stability limits for systems with generator and step-up transformer at one end and step-down transformer and synchronous motor at the other end, the generator and motor being identical in electrical and mechanical characteristics, and the voltage being maintained at 220 kv. on the high voltage side of the transformers. Fig. 16 shows the stability limits for the same lines fed into an infinite bus at the receiving end, that is, the voltage at the receiving end is maintained constant at 220 kv. and the inertia of the apparatus at the receiving end is assumed to be infinitely large. In both cases the generator reactance in per cent was based upon the delivered power.

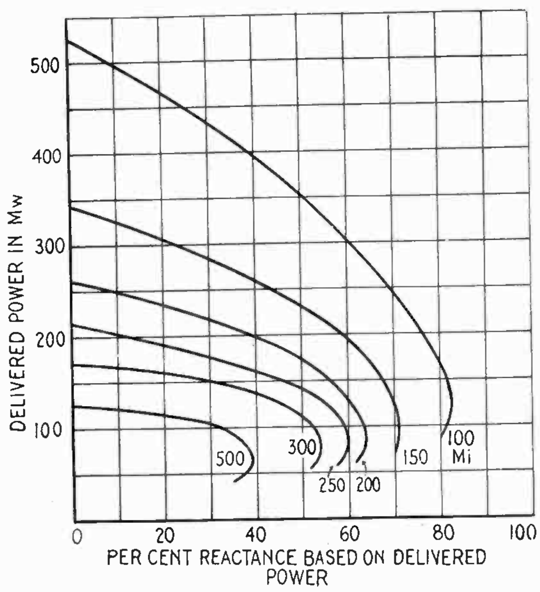

Fig. 15—Stability Limit of 220-Kv. Systems Having Identical Generators and Motors

3-phase, 60-cycle, 795,000-cir. mils aluminum condenser, steel reinforced 29-ft. equivalent spacing

The curves of Figs. 15 and 16 may be used in estimating the static stability of systems by considering how the particular system approaches either of these conditions upon which the calculations were based. These curves will also be found useful in comparing the relative effects of generator reactance and length of line upon the stability limits. It should be borne in mind that these results do not indicate the value at which it is desirable to operate the system but rather that they represent the very limit of power which can be transmitted and that the system should be so designed that even during emergency conditions these values should not be approached.

Figs. 17 and 18 show similar static power limits for a typical single-circuit, 110-kv. system. The assumptions as to load were identical.

Four-Machine Problem

A large percentage of the problems met in practise can be reduced to the equivalent of a two generator

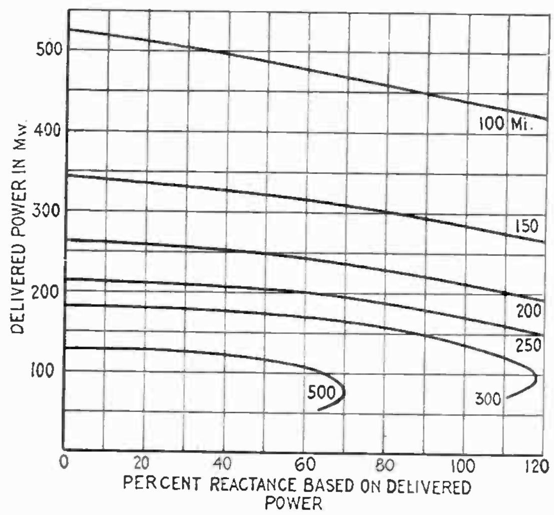

Fig. 16—Stability Limit of 220-Kv. System with Infinite Bus at Receiver

3-phase, 60-cycle, 795,000-cir. mils aluminum condenser, steel reinforced, 29-ft. equivalent spacing

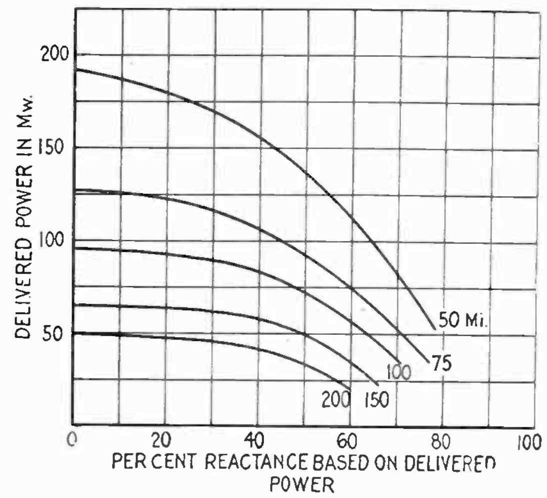

Fig. 17—Stability Limits of 110-Kv. Systems Having Identical Generators and Motors

3-phase, 60-cycle, 4-0 copper, 13-ft. equivalent spacing

problem— a synchronous generator at the sending end and a synchronous motor or generator supplying a local load at the receiving end. There exist, however, a large number of problems which can not be so simplified. A particular case, and one with which this paper is largely concerned is that of ascertaining the effect of an intermediate condenser station in improving the stability limit. This type of problem has been termed "the three-machine problem," because, in the general case it involves three sources of synchronous e. m. fs. The solution of this problem immediately permits of the solution of a large number of problems previously considered too involved or complicated. The number that may be so solved are fewer than those that may be solved by the two-machine problem. There still remain a large number of problems which lie beyond the scope of either the two- or three-machine problem. The solution of some of these, inherently involve the addition of another source of synchronous e. m. f., requiring the solution of the "four-machine problem." A particular case of this type and one with which this paper is concerned, is that of a transmission system with two intermediate condenser stations.

The circuit conditions for the "four-machine" problem referred to previously are completely defined by the following equations:

$$\left.\begin{aligned} \mathbf{I}_a &= \mathbf{Y}_{aa}\,\mathbf{E}_a - \mathbf{Y}_{ab}\,\mathbf{E}_b - \mathbf{Y}_{ac}\,\mathbf{E}_c - \mathbf{Y}_{ad}\,\mathbf{E}_d \\ \mathbf{I}_b &= -\,\mathbf{Y}_{ba}\,\mathbf{E}_a + \mathbf{Y}_{bb}\,\mathbf{E}_b - \mathbf{Y}_{bc}\,\mathbf{E}_c - \mathbf{Y}_{bd}\,\mathbf{E}_d \\ \mathbf{I}_c &= -\,\mathbf{Y}_{ca}\,\mathbf{E}_a - \mathbf{Y}_{cb}\,\mathbf{E}_b + \mathbf{Y}_{cc}\,\mathbf{E}_c - \mathbf{Y}_{cd}\,\mathbf{E}_d \\ \mathbf{I}_d &= -\,\mathbf{Y}_{da}\,\mathbf{E}_a - \mathbf{Y}_{db}\,\mathbf{E}_b - \mathbf{Y}_{dc}\,\mathbf{E}_c + \mathbf{Y}_{dd}\,\mathbf{E}_d \end{aligned}\right\} \quad (45)$$

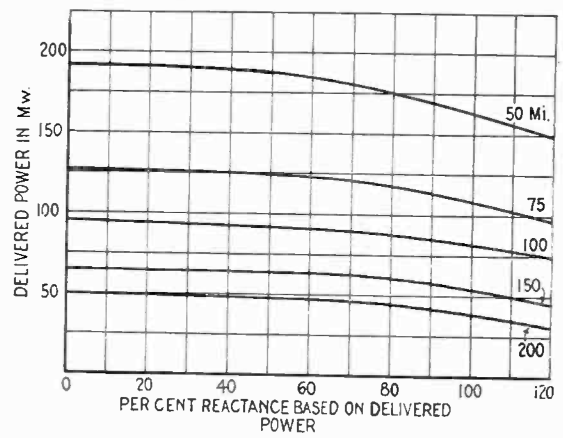

Fig. 18—Stability Limit of 110-Kv. Systems with Infinite Bus at Receiver

3-phase, 60-cycle, 4-0 copper, 13-ft. equivalent spacing

in which the $\mathbf{I}_a$, $\mathbf{I}_b$, $\mathbf{I}_c$, and $\mathbf{I}_d$ are line currents and $\mathbf{E}_a$, $\mathbf{E}_b$, $\mathbf{E}_c$, and $\mathbf{E}_d$ the voltages to neutral. As shown in the Appendix I the necessary conditions which must be fulfilled so that the system remains in synchronism are

$$\left.\begin{aligned} c &> 0 \\ b &> 0 \\ a\,b - 9\,c &> 0 \\ \Delta - b &> 0 \\ a^2 - 3\,b &> 0 \end{aligned}\right\} \quad (46)$$

in which a, b, c, and Δ, defined in the Appendix, are functions of the circuit constants, system voltages and inertias of the machines.

All of these conditions must be fulfilled simultaneously. The failure of any one is sufficient proof of instability. In problems of a given type one of them will be found to fail before the others and after establishing the particular one, it will be necessary to consider only this one condition.

The problem involving two intermediate condensers with synchronous machines at each end of the line has been chosen for discussion because of its important bearing on long distance power transmission. The condensers were assumed to have zero impedance and the resistance and charging current were neglected. Theoretical analysis of this case indicated that the c condition was the limiting one. It further showed that the stability limit occurred when the angle between any two adjacent machine voltages became equal to $\pi/2$. This conclusion is independent of the inertia of the machines, of the magnitude of machine voltages, and of the location of the condensers.

Three-Machine Problem

The problem involving three synchronous machines is a special case of the four-machine problem. A detailed treatment of this problem is given in the unabridged paper. An important application of the three-machine problem is for the case of one intermediate condenser station, the discussion of which follows in the next section.

Stability Limits with Intermediate Condenser Stations

An important application of the theory and methods developed is for the determination of the stability limits of transmission systems with synchronous condenser stations located at intermediate points along the transmission line. This is of particular interest at this time because of its bearing on long distance power transmission. The problems involving one and two intermediate synchronous condensers are special cases of the three- and four-machine problems in which power input and output of the intermediate machines, except for losses, are made equal to zero.

Three general questions arise as to the intermediate condenser station under static conditions, namely, location, voltages to be maintained, and condenser characteristics.

Location of one intermediate condenser for a symmetrical system is clearly at the midpoint of the series impedance of the system regardless of the characteristics of the condenser station itself. With two intermediate condensers the answer is less simple. With zero impedance on a symmetrical system the condensers should be located so as to divide the system into three equal sections. With finite condenser impedance the middle section should be of relatively less impedance than the end sections. With finite impedance condensers the variations from the best theoretical location will have relatively little effect on the stability limit, consequently power system layout need not be handicapped by a requirement to obtain the theoretically best location of condensers at intermediate points.

In regard to the voltages to be maintained there is, undoubtedly, an advantage in maintaining them at as high values as permissible without reduction of voltages at other points. Practically, this means that the voltage at condenser stations should be maintained on the high voltage line at the highest permissible value.

With respect to the characteristics of a condenser this subject can best be discussed by showing the results of calculations. The first case considered is that of one intermediate condenser located between the sending and receiving ends of 220-kv. transmission systems of various lengths. The sum of generator and transformer reactances was assumed in every case to be 12.5 per cent on 100,000 kv-a., and their resistances were neglected. The voltage was assumed to be maintained at 220 kv. on the high-voltage side of the transformers at the generating, receiving, and intermediate condenser stations. The best simple approximation of most of the receiving systems met in practise is the assumption of infinite capacity of the receiving end; that is, zero machine impedance and infinite inertia. It was shown in the discussion of the three-machine problem that

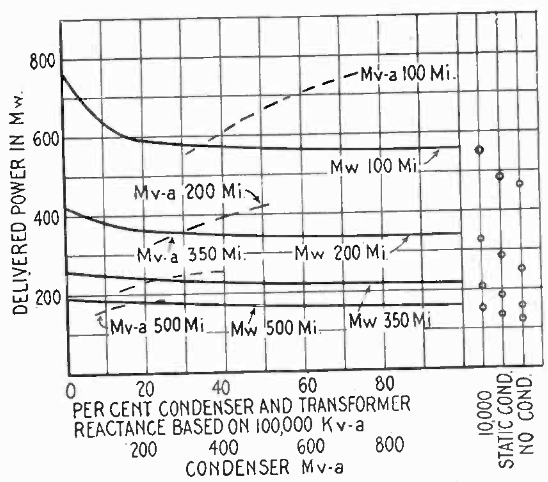

Fig. 22—Stability Limit of 220-Kv. Lines of Various Lengths with One Intermediate Condenser Station

3-phase, 60-cycle, 795,000-cir. mils aluminum condenser, steel reinforced, 29-ft. equivalent spacing, generator and transformer reactance, 12.5 per cent based on 100,000 kv-a. infinite bus and inertia at receiver

when the inertia of one machine was infinite, static stability limits were independent of the inertia of the other two machines. In Fig. 22 are shown the results of calculations of the stability limits of transmission lines of various lengths plotted as a function of the reactance of the condenser and its transformer. In addition, the condenser capacity required at the stability limit is shown by the dotted lines. In estimating the stability limits of particular systems it will be found convenient to make use of the curves showing condenser capacity required at the stability limit in order to convert the impedance base from 100,000 kv-a. to the base corresponding to the capacity considered. At the right of Fig. 22 the following data are plotted:

1. The stability limit of systems with condensers having the extremely high impedance of 10,000 per cent.

This corresponds to the condition of an essentially constant current condenser.

2. The stability limit of systems with variable capacity static condensers located at the same points as synchronous condensers. In this case the condenser capacity was made variable to maintain the transmission voltage constant at 220 kv.

3. The static stability limit of the line alone, that is, without any apparatus at the intermediate points.

Similar calculations were made for the 350-mile line with two intermediate condenser stations instead of one with the results shown in Fig. 25.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of Mr. W. R. Ellis, who performed most of the calculations in connection with the paper.

SUMMARY

The principal features of this paper may be summarized as follows:

For static stability calculations, power systems may be represented by a network with constant impedance and admittance branches with as many terminals as the number of synchronous machines requiring individual consideration. This method is justified because, as developed in the paper, loads may be represented by the equivalent constant admittances and synchronous machines may be replaced by their equivalent impedances.

A criterion for static stability of systems is presented together with formulas for the calculation of the two-, three- and four-machine cases.

It is shown that the maximum angle between machines for which synchronism can be maintained is, in general, somewhat dependent upon the inertia of the synchronous machines. Under some conditions synchronism can be maintained between two machines operating at angles greater than $\pi/2$. The delivered power corresponding to definite excitation of machines will, in general, be a maximum for a smaller angle than the maximum stable angle. While the investigations have shown that synchronism can be maintained in regions heretofore considered inherently unstable, operation in such regions is held to be inadvisable.

There are a number of generalizations which may be made as to the limiting stable condition.

For the two-machine problem the limiting angle is (*a*) $\pi/2$ when the inertias are equal, and (*b*) is greater or less than $\pi/2$ when the inertia of the receiving apparatus is greater or less than the inertia of the supply apparatus, respectively, and (*c*) is equal to $\pi/2$ and independent of inertia when resistance is negligible.

The limiting stable angle with one or two intermediate condensers of zero impedance and system resistance negligible is $\pi/2$ between adjacent sources of e. m. f. With finite-impedance condensers on a symmetrical system with resistance negligible the limiting angle is independent of the inertia of any of the machines.

The results of calculations of the stability of practical transmission lines indicate that large increases in static limits are obtainable with intermediate condensers. Small variation from the theoretically best location has relatively little influence on the stability limit. The improvement in stability due to an intermediate condenser is of course larger with low values of machine impedance but even a high-impedance condenser of the synchronous type will show marked advantage over static condensers which are unsuitable for this application.

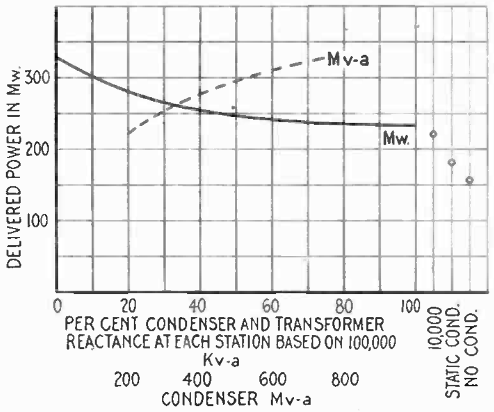

FIG. 25—VARIATION OF STABILITY LIMIT OF A 350-MI., 220-KV. LINE WITH CONDENSER IMPEDANCE

350-mi. line, 220-kv., 3-phase, 60-cycle, 795,000-cir. mils aluminum condenser, steel reinforced, 29-ft. equivalent spacing, generator and transformer reactance 12.5 per cent based on 100,000 kv-a. Infinite bus and inertia at receiver

RAILROAD YARD LIGHTING

In a report on railroad yard lighting recently presented at the annual convention of the Illuminating Engineering Society it was stated that prior to the development of a satisfactory system of electric lighting, night operations in railroad yards were carried on by the aid of hand lanterns. The hazards to the workmen and the equipment were very great. Men were injured, cars and contents damaged, material was stolen and all work materially slowed up. Studies made for devising means of expediting cars through the yards have led to the lighting of the entire trackage by systems of general illumination. The results were reported as very gratifying and showed an economy and efficiency in operating conditions, richly rewarding the railroads for the small expenditure necessary.

The study went into detail on all the different varieties of yard layout and kinds of work needed and discussed the lighting arrangement and the intensities required to meet the various specifications. The need of proper servicing, which applies to all lighting, was emphasized to avoid losses due to accumulated dirt and the effect of slowness in replacing burned out lamps. All lighting systems are arranged to avoid confusion with switching signals.

Electric Welding

Report of the Committee on Electric Welding*

To the Board of Directors:

It is the object of this report to give to the members of the Institute an idea of the commercial importance of Electric Arc Welding.

In such a report as this, the subject falls into two main divisions: Electric Arc Welding, in which the heat for doing the work comes from an arc drawn between the work and an electrode; and Resistance Welding, in which the heat comes from the electric resistance to the passage of a large alternating current across the abutting edges of the parts to be joined.

Electric Arc Welding is done by the *carbon arc* process and the *metallic arc* process. In the carbon arc process direct current is used and the arc is drawn from the work to a carbon electrode. In the metallic arc process either direct or alternating current may be used, but direct current is generally preferred and the arc is drawn between the work and a metallic rod, which melts into the work.

The carbon arc process was first used, on a commercial scale, fifteen or twenty years ago for the repair of steel castings. It has come to be accepted as the standard method of repair for minor defects in such castings. Practically all the steel foundries use this process and most of the 600,000 tons of steel castings made in this country each year have minor defects repaired by the carbon arc welding process.

Locomotive Boiler Repairs

The metallic arc first came into commercial importance in 1914 in the repair of marine engine parts on some interned German ships. Since that time, this process, has been used by the railroads to an increasing extent for the repair of machinery of all sorts.

At the present time, it is safe to say that the locomotive which drew the train that brought you to this Convention had all the flues welded in the works that built the locomotive in the first place, and that the boiler has had some repairs by the metallic welding process made on it in the repair shops of the road owning the engine. The fact that locomotive boiler repairs are so frequently made is very striking evidence of just what the process can do, for electric welds will stand up in a boiler of a locomotive carrying 200 to 250 lb. of steam and traveling over the rails at 60 mi. or more per hour. Electric welding is used for the repair of many parts of the locomotive beside the boiler. It is used for building up worn treads on driving wheels, worn guide bars, repairing broken frames, and for the repair of many other parts of the locomotive.

Mr. Wanamaker, one of the members of your Electric Welding Committee and Director of Welding for the Rock Island Systems has stated that the use of welding has enabled them to make repairs so much more promptly that they are able to get the same service with 20 locomotives less than would have been necessary with the old methods of repair.

To put it another way, welding has enabled the Rock Island System to reduce the investment in locomotives by over $1,000,000 without decreasing the number of engines available for service. This is in addition to the savings effected by the use of welding over the older methods of making the same repairs.

I quote from a letter from Mr. Wanamaker;

> "The latest estimate states that the railroads of this country now have invested approximately $4,000,000 in arc welding equipment, covering some 3500 welding equipments which are saving the railroads approximately $1,000,000 per month, or $12,000,000 per year. It is possible that the indirect savings will be greatly in excess of this figure. However, it is not the policy of railroads to assign a value to the indirect savings.
>
> "The use of electric arc welders for battered rail ends and special work rail is just now beginning to take strong root. I, personally, feel that the intelligent use of the electric arc welder has paid probably the greatest net return ever secured from any investment made in railway equipment, and I am somewhat at a loss as to why its use has not been more strongly furthered and fostered by the A. I. E. E."

Mr. Churchward, another member of your Committee, has a number of photographs showing the repair of an 8000-lb. bronze propeller by the addition of about 1000 lb. of bronze at a great saving in cost; he also has some photographs of the building up of the copper collector rings of a 1000-kw. rotary.

As important in repair and replacement work as is the use of electric welding, recent experience shows that its greatest field is as a new method of manufacture of new products.

It is clear that if a welded joint in steel can be made equal in strength to the plates to be joined, great economies in production can be obtained.

Following will be found a number of examples of construction on a large scale, in which welding has replaced riveting and the older methods of joining steel plates.

*Committee on Electric Welding:

J. C. Lincoln, Chairman

C. A. Adams,	Alexander Churchward,	Ernest Lunn,
P. P. Alexander,	O. H. Eschholz,	J. W. Owens,
C. W. Bates,	F. M. Farmer,	William Spraragen,
Ernest Bauer,	H. M. Hobart,	H. W. Tobey,
A. M. Candy,	C. J. Holslag,	Ernest Wanamaker.
	C. L. Ipsen,	

Presented at the Summer Convention of the A. I. E. E., Detroit, Mich., June 20-24, 1927.

Shipbuilding

So far as we know, the first all-welded vessel was built in Ashtabula, Ohio, about 1914, for use on the Lakes. This was a boat 40 or 50 ft. long, used as a fishing boat. It has been in satisfactory service ever since it was built. On one occasion, a year or so after it was built, the plates near the waterline were bent by smashing through ice on the Lake, but no joint opened up.

Mr. Owens, one of the members of your Committee on Arc Welding says:

"A welding research and development program which was started by the Navy Department at its Norfolk Yard in 1918, under the direction of Mr. James W. Owens, until in 1926, he became affiliated with the Newport News Shipbuilding and Dry Dock Company, as its Director of Welding, has resulted in securing the confidence of the Navy in welding, with the result that it is now being used extensively in new construction and repair of naval ships. Its battle towing targets, which are 45-ton structures and of 3/8-in., 1/2-in. and 1-in. plate material, are now completely metal arc welded, 15 such targets being constructed to date. The shell deck and two water-tight bulk-heads of a pontoon for a 100-ton derrick have been completely welded. It is being extensively used in the construction of the light cruisers recently authorized by Congress, and an estimated saving of $250,000 is being secured by its use in the modernization of its capital ships.

"The Coast Guard Cutter *Northern* which was recently launched at this yard, has its deck and superstructure very largely metal arc welded. Its rudder is completely welded and four seams at the waterline are welded in addition to being riveted in the usual manner, so as to enable the hull to more effectively resist ice pressure in Arctic service. Practically all oil, gas, and fresh and salt water tanks of ships being built at this yard, together with their piping systems, are being welded, and steps have been taken to completely weld all of the ventilating system ducts. During 1926 a total of 165 welded tanks was built and it is becoming standard practise to weld deck beams directly to bulkheads with or without the use of plate collars. Two completely welded condenser shells for merchant ships have recently been completed, together with the exhaust pipes for several ships."

Welding Structural Steel for Buildings

The steel frames for a number of buildings have been made by the arc welding process. In 1925 a three-story garage building, having a ground area of about 75 by 150 ft., was erected by the Wellman-Seaver-Morgan Company of Cleveland in Canton, Ohio. Although this was the first building arc welded by this firm, no difficulty was experienced in the erection, and they report a saving of 25 per cent in cost of erection, as compared with the cost of the same building riveted.

The largest building erected by arc welding to date has been that erected by the Westinghouse Electric & Manufacturing Company of Sharon, Pa. Mr. A. M. Candy, a member of your Welding Committee, was in general charge of the work and has written a very complete and valuable paper describing the work.

The building at the Sharon, Pa., Works of the Westinghouse Electric & Manufacturing Company is 70 by 220 ft., by 80 ft. high and required 790 tons of metal.

The following are some extracts from his paper:

"That arc welded joints can be constructed in such manner as to develop fully the ultimate strength of the structural members connected.

"That a steel I-beam of given section and length will sustain a far greater load if fixed at its ends by a suitably designed arc welded joint than if supported by standard riveted connections consisting of top and bottom angles. A 9-in. standard I-beam framed between rigid upright columns 8 ft. apart by means of specially designed welded connections sustained a load 25 per cent greater than a beam of the same size and length framed between columns by means of riveted top and bottom angles 1/2 in. thick.

"A plate girder, assembled by welding and consisting of nothing but sheared plates has a far greater strength than a riveted plate and angle girder of the same weight, due to the better distribution of the steel in the cross section. A 15-in. plate girder, assembled by welding and simply supported on a 14-ft. span, developed more than 50 per cent greater strength than a riveted plate and angle girder of the same depth and the same weight.

"The prevailing impression among the witnesses was that these tests demonstrated the superiority of welded connections to riveted connections in every case where direct comparisons were made, and brought out two general facts:

"1. That complete continuity of lines of beams can be obtained in welded construction, whereas it is well known that this cannot be done in riveted construction.

"2. That in a welded building it will be possible to make every joint develop full strength of the main members, whereas in a riveted building many joints are weaker than the members due to the weakening effects of the rivet holes and the weakness of steel angles which have to be used for transmitting tension between two members at right angles to each other.

"It was proved that a welded plate girder was 50 per cent stronger than the riveted girder of relative depth, length and weight.

"An Olsen testing machine, capable of applying 40,000 lb., was used."

In 1924 near Toronto, Canada, a highway bridge nearly 700 ft. long was erected by arc welding.

The American Welding Society has an active committee on Structural Steel Welding, the chairman of which is Mr. James H. Edwards, of the American Bridge Company. This committee is collecting data and making extensive tests to provide structural engineers with the fundamental information necessary to properly design an arc welded structure. The work of this committee is to provide the structural engineers with the information as to how long a weld and how thick a weld to use to give a strength of joint equal to the strength of the members being joined.

Pipe Lines

The carbon arc has been used for the manufacture of almost 90 mi. of pipe nearly six feet in diameter, for supplying water to Oakland, California, and the other Bay Cities in the vicinity.

Following are some quotations from a paper read by J. F. Lincoln, March 17th, 1927:

"As an illustration, The Mokelumne River pipe line which was made arc welded, is 90 mi. long and contains 78,000 tons of steel. If this same pipe line with the same strength of joint and the same ability to carry water had been made riveted, it would have required 128,000 tons of steel to accomplish the purpose, and the cost would be at least $3,000,000 more.

"The best illustration of the economic advantages of the above ideas are shown in the Mokelumne River Pipe Line, which brings the water supply a distance of 90 mi. to the East Bay Municipal Utility District in California. This line runs from the Mokelumne River to Oakland and supplies the water for all of the Bay Cities, with the exception of San Francisco. This job required, for the manufacture of the pipe, 78,000 tons of steel, the thickness of this steel being 3/8 in., 7/16 in., 1/2 in., 9/16 in. and 5/8 in., depending upon the part of the line in which the pipe was to be placed. It was manufactured in two lines—the first running from the San Juaquin River to Oakland and the second, from the Mokelumne River to the San Juaquin River.

"The first section of this, running from the San Juaquin River to Oakland, is at the present time completed and has been under pressure now for a considerable period. Because of the newness of arc welding, the engineers determined not to proceed with the second section of this pipe line until after the first section had been completed. They have, within the last sixty days, let the contracts for the second section, the specifications remaining identical in every particular with those of the first, thus showing the complete success of this method of construction.

"It is also interesting to note that, in spite of the fact that no such work as this had ever before been attempted, insofar as thickness of plate, diameter of pipe, etc., were concerned, the first 40 mi. were completed more than one month ahead of time, and this in the face of the fact that the building for the manufacture of this pipe had to be constructed, machines designed and built, and the whole plant put into operation.

"The second section of this line, which is to be done in the same time as the first, will undoubtedly beat its schedule by many months.

"The description of this line and of the problems involved, as concerns welding, can probably best be explained from the specifications which were drawn for it and under which the pipe was manufactured. The specifications covering the welding machines provided that the welding shall be done with an automatic electric welding machine, designed specifically for the work covered by those specifications. This machine comprised among other necessary parts, a traveling carriage for carrying the carbon electrode, arranged to move, at a controlled rate, along a tract located inside of the pipe above the bottom seam, and water-cooled mandrels located on the outside and inside of the pipe and extending along this seam throughout its length.

"Next, the method of testing was specified as follows:

"*Hydrostatic Test of Pipe Specimens.* After each section of the pipe has been welded, it shall be subjected to a hydrostatic test under internal pressure sufficient to develop a tensile stress of 20,250 lb. per sq. in. of plate, and while under this stress, shall be hammered vigorously on both sides of the weld with a 10-lb. hammer not more than once in every foot of pipe section. The pressure shall then be increased sufficiently to produce a tensile stress of 23,000 lb. per sq. in. of plate and so held until the efficiency of the seams can be determined by inspection. In the event of failure of the pipe section under this test, the contractor shall have the right to re-weld the pipe if practicable and re-submit it for test.

"*Rejection.* Any section of pipe that does not conform to these specifications may be rejected.

"It is claimed, in connection with this, that it is probably the most severe test that was ever put on any pipe made by any process, and it is only necessary to say that possibly no other method of manufacturing large pipe now known could pass the specifications for test as outlined in these specifications. As a matter of fact, there are a number of cases where the test pressures were carried up so high and so far beyond the statement in the specifications, that a permanent set was actually put in the steel of the pipe. In one case that came to the author's attention the diameter was increased by more than three inches because the pressure that was used in testing went considerably beyond the elastic limit of the steel."

Use of Welding to Replace Castings

Due to the fact that rolled steel has three or four times the tensile strength of cast iron, and at the same time costs from one-third to one-fourth as much per pound, it is possible to make many structures from rolled steel shapes by arc welding to replace cast iron at a very great saving in cost.

For instance, a certain cast iron bed plate weighed 560 lb., and at 5.5 cents per lb., cost $30.80. The cost of machining this was 90 cents, making a total cost of $31.70.

The corresponding base of angle iron welded up (with bosses welded in) weighed 233 lb., cost $6.38 for material and $1.07 for cutting off, welding, and drilling, or a total of $7.45. In addition, the welded base will stand any abuse that can be given to it, while cast iron bases break if not carefully handled

One of the first welded products we happened to know about was a compensator can. This can was formerly made of cast iron, very heavy, very expensive, and liable to leaks which made it necessary to reject part of those the foundry delivered. The arc welded can, for the same purpose, looked better, weighed less than 20 per cent of the old cast iron can, and cost less than 10 per cent.

The General Electric and Westinghouse Companies are using arc welding to an increasing extent in the manufacture of their product, though the process can be and no doubt will be used to a much greater extent in the future.

A paper by Mr. Warner, in the March issue of the American Welding Society *Journal*, gives an account of some of the work being done by the General Electric Company at the present time.

The Company with which your Chairman is connected has brought out a book "Arc-Welding, the New Age in Iron and Steel," in which there are hundreds of illustrations of structure of all kinds built by Electric Arc Welding.

This process makes possible the manufacture of many structures that are both better and cheaper than the same structures were when made of cast iron.

Resistance Welding

This process was invented by Elihu Thompson, in the early days of electric development, and at the present time is used for the production of some millions of feet of tubing every month. Practically all of the tubing used in automobiles and in the construction of bedsteads, is made by this process.

As you all known, a million dollars is a small sum when talking about automobile products, and as this process is used to a greater or less extent in the construction of all cars, we can be sure that the cost of the car you drive would be noticeably greater if it were not for the saving in cost of construction made possible by this process. The all-steel automobile body is coming into use and thousands of these bodies are made every year in which the seams are welded by this process.

The following is quoted from a letter from Mr. H. W. Tobey, one of the members of your Committee and in charge of work of this kind at the Pittsfield Works of the General Electric Company:

"Our large spot welders are used in regular production for thicknesses of steel ranging from two pieces of 1/4 in., two pieces of 3/8 in., up to two pieces of 1/2 in., making a maximum total thickness of 1 in. This method has replaced to a very large degree the former practise of riveting.

"Spot welding is also used throughout the plant for a variety of purposes where it is desired to join various parts of equipment together in a strong and effective manner at a reasonable cost.

"Resistance line welding has been found to be of especial value wherever it can be applied in mass production to structures composed of sheet material of suitable shape and in thicknesses up to and including two pieces of 1/8 in. stock.

"All factors entering into the several types of resistance welding, including butt welding, spot welding and line welding, are under perfect control so that after correct settings have been obtained for current, pressure, speed, etc., the results can be duplicated with unerring regularity as long as the characteristics of metal remain the same. The material is brought to precisely the right temperature and strong, reliable welds uniform in character and appearance are assumed. The fact that no hood or eye protection through the use of colored glass is required, is also a distinct advantage."

J. C. Lincoln, *Chairman.*

Discussion

J. D. Noyes: I should like to ask Mr. Lincoln if the committee has come to a conclusion as to the comparison or disadvantages between alternating current and direct current.

E. C. Crittenden: Recently there has come to my attention a field in which it appears that some companies are finding other methods better than electric welding. Mr. Wanamaker in the report, says, with regard to railroad practise, "The use of electric arc welders for battered rail ends and special work rail is just now beginning to take strong root." I understand also that the street railways are using arc welders in putting up crossings and other special work, but for the regular rails, the straight-away welding, they are finding other methods better.

It appears to me that probably the difficulty arises from the fact that they are using the old method of connecting rails with only a slight modification for welding. Two rails abutting, end to end, are held together by two fish-plates. The two plates are clamped on the sides of the rails and then welded around the edges. This method has the effect of stiffening that part of the rail and in service, the rails often break at the end of the welded and stiffened portion, presumably because the stresses are localized there. I believe some companies have abandoned arc welding of rails because they get such breakage. Is there available any electrical welding method which will avoid this difficulty?

F. W. Funk: Mention has been made in the report of several buildings that have been electrically welded. We have in Youngstown a welding company which erected a steel-frame building which was entirely welded; that is, there were no holes punched or drilled—no bolts used in temporary construction. It was a 100 per cent welded building. I think that is quite an advance because if we have to punch structural shapes, it offsets the saving.

Electric welding is coming into use for very heavy plate work and tank work. One concern which manufactures very large oil tanks for use in the oil fields is going into the electrical welding of heavy plate tanks. It is probable that the process will be an automatic welding process.

Another company is producing thousands of tons of complicated rolled shapes each year which are either seam- or lamp-welded, used principally, I think, in floor beams and roof members. I mention this concern particularly because it has done a great deal in the development of automatic welding machines.

I think Mr. Lincoln is entirely correct in saying that in new construction lies the greatest field for electric welding.

J. J. Shoemaker: I should like to ask Mr. Lincoln if this method of welding is approved by the insurance companies for boiler repairs?

J. V. B. Duer: I think some of these questions that have been discussed are important. The question of workmanship enters into electric welding more than most of us realize. I think if we could be assured that the workmanship on an electric weld was perfect, it would be a more generally accepted practise than it is at the present time.

I am also much interested in the question of the relative values of a-c. versus d-c. welding. I made a rather superficial investigation of the subject a few years ago and came to the general conclusion at that time that the principal objection to a-c. welding was that it involved a low power factor on the circuits to which the welders were connected. That was especially true of 60 cycles rather than 25 cycles. In a place where the welding load amounted to a large proportion of the total, such as it might in a roundhouse on a railroad or some place of that kind, the use of an a-c. welder might be objectionable whereas if a d-c. welder were used the high power factor due to the use of the welding might be obtained and some correction made for low power factor on the other circuits.

J. C. Lincoln: I may be prejudiced in favor of the direct current. It happens that the concern with which I am connected, manufactures d-c. apparatus. That fact has to be taken into consideration in weighing my reply. I believe myself that experience will show that it is easier to make a good weld with a good d-c. machine than it is with an a-c. machine. We feel this way about it; that the art would be advanced more rapidly by doing only good work. Therefore, only the best apparatus should be used. I believe, on the average, for metallic arc welding better work can be done with the direct current than with alternating current.

I think it is true that in some cases railroads which have formerly used the electric-arc method for joining their rails are using other methods at the present time. I have been very much interested in that particular part of the electric-welding art for a good many years. Notwithstanding the fact that there have been a number of failures, the amount of success with electric-welded joints has been sufficiently great so that they are used commercially to a great extent. In my opinion, the failures have been due partly to the cause as pointed out by Mr. Crittenden, but more largely to the fact that the welding methods themselves haven't been as good as we hope they will be some time.

In the electric welding of rails, in some cases at the bottom of the crater when the weld is finished there are hair cracks due to the contraction of the hot metal. Now, it is a fact, of course, that hot metal occupies a larger volume than the same metal when cold. Metal, when melted, occupies 107 per cent of the volume it does when cold. When the metal cools, one of two things happens—either the metal must stretch according to the amount of decrease in volume or hair cracks appear. If the metal is brittle enough, hair cracks appear. If the metal is of the proper quality, it will stretch and take up this decrease in volume.

It is my belief that most of the difficulty in the welding of rails has been due to the fact that the methods in use at the present time produce welds which are brittle so that these hair cracks appear.

Now, a hair crack at the end of the rail will start an incipient break. Take, for instance, a piece of glass. You know that if you start a crack in a piece of glass, the wind strains will finally work that crack further and further through the glass. If you will drill a hole at the end of the crack, you won't find any further trouble. The incipient crack doesn't progress. Something of the same nature occurs in the electric welding where the hair cracks appear. The remedy for that condition is to improve the quality of metal in the weld.

It is a fact that in welding of rails, processes are in use at the present time where these hair cracks are easily eliminated. If the work is properly done, satisfactory results are obtained. If it is not done properly, trouble results.

I believe experience will show that although, as pointed out, you have a weak spot at the welded point in the rail, when the welding is properly done, the weakness is not so great as to develop trouble.

The American Society of Mechanical Engineers has prepared a Boiler Code and this Boiler Code does not permit the use of electric welding to so great an extent as we who are interested in pushing electric welding would like. Electric welding is permitted on some types of pressure vessels but at the present time electric welding is not used on pressure vessels used in boilers.

The American Welding Society has a committee making extensive preparations to test a large number of pressure vessels at the Bureau of Standards to get complete information so that the Boiler Code Committee can feel justified in giving more liberal allowances for electric welding.

At the present time steam boilers are not allowed to be welded by the electric welding process. The queer part of it is that the railroads have been repairing locomotive boilers for years and these boiler repairs made on locomotives are on pressures of 200 to 250 lb. Years of experience in locomotive boilers have shown that method must be used. If you please, from a commercial standpoint, the railroads can't get along without it.

While there has been some trouble from improperly made welds on electric locomotives, the process is in use quite generally and I don't think there is any doubt that it will be used more generally in the future. But to answer the question specifically at the present time, pressure vessels—fired pressure vessels—are not allowed to be electrically welded.

A compilation of earnings in the public utility field has not hitherto existed in any comprehensive statement of monthly earnings similar to the figures collected by the Interstate Commerce Commission for railroads, telephone and other companies. In the future, gross and net earnings of public utilities in the United States will be compiled in a series of monthly reports. The first report will cover a compilation for the period from 1913 to September 1927, and will be available in statistical form from the Department of Commerce.

Abridgment of

Combined Light and Power Systems
For A-C. Secondary Networks

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Synopsis.—The increase of a-c., low-voltage network systems employing automatic sectionalizing equipment has been very rapid. This move has been attended by a diversity of choice of combined light and power schemes for the secondary mains.

Carrying this condition to its logical conclusion may result in an extremely complicated situation for apparatus connected to these mains. There might thus be imposed on the industry as a whole a heavy expense tending to cancel a part of the savings attributed to the advent of the combined system.

A study of the effects on seven types of equipment concerned showed that general purpose motors are hardly more important than most of the other devices. This analysis included not only the applicability of existing apparatus standards to each of the combined systems but also the probable developments that the future may bring. For a comprehensive comparison of the various schemes it was found necessary to consider the commercial as well as the engineering aspects.

If the operating companies decide to employ the combined light and power system universally for secondary networks, it is urged that they will soon apply the practise of standardization to the combinations of connection and voltage. In this regard, due consideration should be given to the bearing of numerous trends in the industry. Widespread discussion of the situation is now desirable.

* * * * *

CLOSE contact with the discussion and use of the various combined light and power connection schemes that are rapidly being adopted as part of a-c. network systems brings the realization that:

a. The gross savings attributed to the combined scheme may be reduced by the expense incurred in the production of suitable utilization equipment.

b. This expense might range from a minimum of 75 million dollars to a maximum of 150 million dollars even under the favorable condition of a single combined scheme adopted universally, and

c. The latter sum may be exceeded if the three principal combinations are continued without the advantage of standardization on one system.

This gives good cause to wonder whether this may not be the proper time to investigate which method of supplying both power and light from the same secondary mains will give the greatest benefit with the least expense to the industry as a whole.

Beginning about four years ago with a single network installation in New York City, the spread of automatic network systems using the combined secondary scheme has been such that 11 cities will have in operation by the end of this year (1926) networks embodying combined secondary schemes of one design or another. Furthermore, early next year, this number will be increased by three, and the possibilities of these networks are now being investigated in at least 16 other cities. The number of cities now interested in this question thus totals 30.

Where two networks are employed, one for light and the other for power, the distribution system may become very expensive and occupy too much space (ducts or pin positions). The combined secondary system, it is claimed, furnishes an economic solution for extending the a-c. network system into areas where lack of space would make very difficult the installation of two separate networks. And—just as in the d-c. three-wire system—the combined method permits the immediate servicing of any customer for either power or light, or both, from the same set of low-voltage mains.

In attempting to avail themselves of the advantages of this system, the operating companies have considered many different combinations of connections and voltages, each scheme admirably suited to the local conditions surrounding its development. Unfortunately, the three-phase schemes differ in the resulting voltages available for light and power, and the existence of the two-phase combined system further increases the number of possibilities.

There are indications that adoption of these various schemes on an extended scale may have considerable effect upon the operation of electrical devices now connected to secondary systems, and result in a more or less complete re-adaptation of many, if not all, of the devices for future applications. To gage the probable consequences of having several different schemes adopted for numerous large distribution systems is impossible without a carefuly study requiring the earnest cooperation of all operating companies.

This paper is offered to show the result of an approximate analysis of what might be the effect on various types of apparatus were networks incorporating any one of the principal combined light and power systems adopted extensively. The analysis included consideration of such major lines as: Lamps—motors and control equipment—appliances—distribution apparatus.

Present Status of Application of Combined Light and Power Secondary Systems

To better understand the nature of these combined

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systems and their extensive application, an outline of their present status may be of value.

Spread of Combined Secondary Systems. During the past 11 years, a city in Tennessee has had a comparatively large three-phase underground network, supplied by numerous feeders and employing 115/199 volts at the utilization devices. Motors up to 50 h. p. are connected to the combined light and power mains even at points between transformer banks. The majority of the motors are the standard 220-volt type; only rarely is a 200-volt motor encountered; and the very few complaints of low voltage due to the use of 199 volts have been remedied in a simple and inexpensive manner by means of small boosting auto-transformers.

About one year ago a city in Louisiana started up

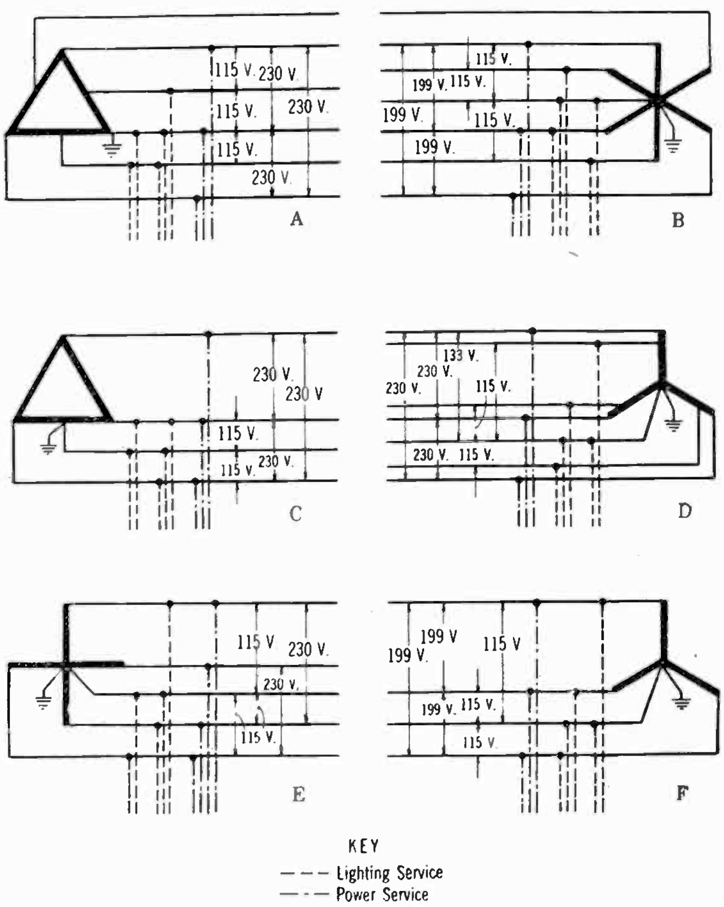

FIG. 1—SCHEMES FOR COMBINED LIGHT AND POWER

a combined light and power network system with nominal voltage of 115/199 volts. Many expected troubles proved imaginary and it was easy to dispose of the few that did materialize.

The combined secondary system was first publicly urged for universal application in this country by Mr. W. C. L. Eglin, who recommended that this scheme, in three-phase form, be adopted as standard for all miscellaneous light and power distribution and street lighting. Active spread of the multiple primary feed low-voltage a-c. network, using combined secondaries and automatic protective equipment started shortly after it was demonstrated by Mr. A. H. Kehoe and Mr. W. R. Bullard in 1924 that this system was successful in operation, and more economical and reliable, than any previous a-c. system.

Some Combined Schemes. The combinations of connection and voltage for combined secondary systems that have been given the most study are indicated in Fig. 1,—*A, B, C, D* and *F* applying to three-phase and *E* to two-phase. The schemes of Figs. 1E and 1F are receiving the most attention at the present time.

Of the network systems now under construction, eleven will use Fig. 1F arrangement, two Fig. 1E, one Fig. 1D, and one Fig. 1C as a preliminary to Fig. 1F. For the majority of the fifteen networks planned and under consideration, Fig. 1F scheme is favored for the underground. For overhead network systems Fig. 1C is planned in one case. In the three-phase distribution systems to which Fig. 1F applies, 125/216 volts is being considered in only one place; for the remainder, about half prefer 115/199 volts at the utilization device and half 120/208 volts.

A. Three-phase Networks. There are indications that a move will be made, as the number of systems using the two principal combined secondary arrangements increases, to change the design of apparatus used on these systems to suit each combination.

Thus, 115/199-volt star systems are likely to require changes eventually in the design of polyphase and other apparatus connected between phase-wires. It is estimated that this would affect up to about one-fifth of all phase-to-phase apparatus, the remainder being used outside of the network areas and on isolated plant systems.

The 120/208-volt star system will probably require changes in design for both apparatus connected between phase-wires and that connected from phase-wire to neutral. An effort to estimate what part of all the phase-to-neutral equipment would be thus affected might place it at about half.

B. Two-phase Networks. For the few two-phase systems, production and stocking of two-phase apparatus will no doubt continue, tending to keep up the prices of all polyphase equipment. Furthermore, the companies operating two-phase systems may have somewhat higher annual charges (2 to 3 per cent) than with the three-phase system.

C. Radial Secondary Systems. It is probable that radial three-phase 110/220- and 115/230-volt distribution systems, some of which use single-phase feed, and other radial systems giving 110 volts or less at the utilization devices, will be confined to miscellaneous load systems in cities, towns, villages, and farms where load density is light; to bulk loads fed by operating companies; and to isolated plant systems. These would thus ultimately take a little less than half of all phase-to-neutral apparatus and four-fifths of all phase-to-phase apparatus, and necessitate maintaining the present lines of equipment in addition to all new lines.

The requirement of supplying various standard lines of equipment for a plurality of distribution groups will have a tendency to increase apparatus development and distributing costs, and therefore the prices of apparatus. Furthermore, an increase in the number of classes of apparatus and of types of distribution system may be expected to add complications in the choice of equipment having the proper rating, and confusion to customers by change of system in moving from city to city. With the higher prices, these factors would tend to reduce consumption of apparatus and electric energy.

Standardization as a Remedy. These troubles could be avoided by the adoption, as a standard for combined light and power secondary systems, of that scheme which fits in best with existing standards.

Qualitative Analysis for Apparatus Connected to Secondary System

The result of an investigation into the effect of the various combined schemes upon the operation and manufacture of each of the types of apparatus connected to secondary systems will be presented as a Qualitative Analysis. The combinations chosen were 115/199 volts three-phase star, 120/208 volts three-phase star, and 115/230 volts two-phase five-wire, since they are now in use; also 125/216 volts and 110/190 volts star because there appears to be some question as to the possibility of employing them.

Effect of Change to Combined Light and Power System for Three-Phase Star Secondary Networks

This analysis was made on the assumption that all of the systems that may be networked would adopt the three-phase four-wire scheme, while all other systems would continue to be served by the three-phase radial method.

1. *Effect on Small Motors.* 110/220 volts is the present standard for this line, with allowable variation of 10 per cent plus or minus.

Polyphase Motors: 125/216 Volts. There would be no trouble with this voltage.

120/208 Volts. Practically all standard 220-volt ratings could be used as they stand. New designs could be reduced to a minimum by having it generally agreed that 220-volt motors will be satisfactory for operation on 208-volt networks and that no change in the nameplate will be required.

115/199 or 110/190 Volts. A separate line of motors would have to be brought out and the expenditure involved would be fairly large; it would even be excessive for 190 volts if the greater production of the future is considered.

Single-Phase Motors, 2:1 Voltage Winding: For any voltage of the combined three-phase four-wire secondary system this class of motor must operate either across two phase wires or from phase-wire to neutral. As this does not give a 2:1 ratio the tendency would be to design the motor winding for sufficient power on the series connection and with sufficient material to withstand the voltage to neutral on the parallel connection.

This would result in a motor considerably larger and from ten to fifteen per cent more expensive than the present standard. Double guarantees would be necessary and unusual care in application would be required to ensure that sufficient capacity be always available for the connection between phase-wires.

It is therefore considered hardly advisable to introduce 2:1 voltage winding motors for combined three-phase four-wire secondary networks.

Single-Phase Motors, Single Voltage Winding: The present 220-volt ratings could be employed for 216 or 208 volts on network systems, but the risk at 199 or 190 volts would require the development of a separate line for these voltages. It is anticipated that if the combined light and power systems where potentials higher than 115 volts are actually obtained at the motor terminals become more numerous and are in the form of networks, whereby closer secondary voltage regulation is obtained, trouble may be experienced due to overheating, noise, increased starting current, and lower efficiency and power factor. This would be particularly true for 125 volts, which means that motors for this voltage would have to be redesigned almost immediately.

It is reasonably certain that difficulty would arise should customers begin to order 120-volt motors, making it necessary to give guarantees and eventually to mark the nameplates at 120 volts. Building and stocking a new line of 120- or 125-volt motors as a parallel to the present 110-volt line would require a fairly large expenditure. In addition, there would be considerable expense and confusion on the part of the utilization device manufacturers, for they would have to buy motors of both classes and carry large stocks at their factories and distributors' warehouses.

2. *General Purpose Motors.* 110/220 volts is the existing standard for these motors, with permissible variation of 10 per cent plus or minus.

The analysis, except for the sections on characteristic curves, is based on actual performance data for all sizes from 5 to 150 h. p. in all lines.

125/216 Volts: There would be practically no difficulty with this voltage.

120/208 Volts: Starting Torque: Since starting torque varies approximately as the square of the voltage, the application of 208 volts to a 220-volt motor results in a reduction of about 11 per cent in starting torque. At least 50 per cent of the standard 220-volt ratings would still give satisfactory torque at 208 volts plus or minus 10 per cent. The expenditure in development and other costs would be large for the motors that would require rewinding.

Were the principle of 5 per cent plus or minus voltage regulation in secondary networks established, these changes could be avoided, provided only a small number of 220-volt motors would require rewinding to operate satisfactorily on 208 volts. Where this procedure might result in too low a starting torque because of the reduced voltage at starting, the motors might be thrown directly on the line at 208 volts.

Characteristic Curves: The characteristic curves in Fig. 2 were taken on a typical standard 220-volt three-phase squirrel-cage induction motor.

115/199 Volts: Starting Torque: The starting torque of a 220-volt motor is reduced 18 per cent when a voltage of only 199 volts is impressed. The number of 220-volt ratings that would give satisfactory torque at 199 volts plus or minus 10 per cent ranges from about 50 per cent of the total to a percentage considerably below this.

The decision between one line or two in this case might lean towards the latter on account of the large number of motors that would require rewinding. Due to the greater number of ratings involved the expendi-

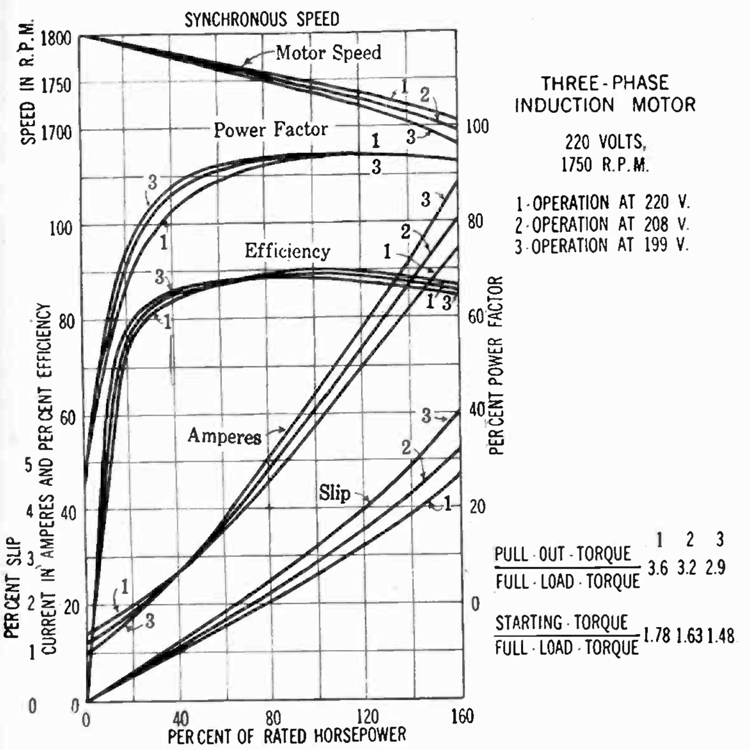

Fig. 3—Motor Performance Curves

ture would be much larger than in the case of 120/208 volts.

Characteristic Curves: Curves 3 and 1 in Fig. 2 indicate the differences in characteristics of a typical general purpose motor at 199 volts and 220 volts.

110/190 Volts: A decrease to 190 volts from the present standard of 220 volts is very great. In addition, to provide for a further variation of 5 per cent (if this principle be accepted generally) widens the range to a point where difficulties might be encountered with the majority of existing motors. Should 10 per cent voltage variation be maintained as the accepted custom, the conditions would of course be even worse.

If the original guarantees were required, the adoption of 110/190 volts would necessitate two lines and the expense would be so great as to be uneconomic.

3. Motor Control Equipment. 220/440 volts is now standard for this apparatus, with allowable variation of 10 per cent plus or minus.

A new National Electrical Code rule permits the use of two trip coils with a fuse in the third phase for motor starters on three-phase four-wire systems with grounded neutral such as are employed in the majority of combined network systems. This may be used as an expedient to make unnecessary the equipping of existing control apparatus with additional trip coils when the secondary distribution system is changed to the combined light and power type.

It is reasonable to expect, however, that considerable experience with or study of the combined secondary system for networks will bring about a demand for that form of apparatus which suits the application best; in this case, three-coil protection in starters for three-phase motors.

This would necessitate rearranging all general purpose motor controller designs to provide the third trip coil, and that would entail a large item of expense.

125/216 Volts: The present standard coils could be used in most cases, but where the voltage is low special coils would be required.

120/208 Volts: 115/199 Volts: 110/190 Volts: Any of these voltages involves adding at least 33 per cent to the number of a-c. coils in stock and the maintaining of a double set of standards since the original standard of 220 volts will still hold for other than network systems. The expense of all necessary changes would be large, especially for 190 volts.

4. Safety Switches. 125/250 volts is standard at present for these switches and is the maximum rating.

To comply with the latest safety code ruling it will be necessary to change the construction of the standard triple-pole entrance switches by adding a neutral strap, for such services as will be three-phase four-wire. It is probable that this will apply to all standard sizes.

Where four-pole general purpose switches have been employed on delta-connected circuits, there might be a demand for three-pole switches with solid neutral connection. Motor starters having thermal cutouts may have to be redesigned to include an additional thermal cutout.

The expenditures thus incurred will be considerable.

5. Distribution Transformers. 115/230 volts is the standard now. A tolerance of 5 per cent plus is allowed for single-rated transformers. The majority of transformers are triple-rated at 110/115/120 volts, and 120 volts is the allowable upper limit.

125/216 Volts: The salient effect is on exciting current, which increases about 300 per cent when a 115-volt transformer is stressed to give 125 volts. As this is decidedly beyond the allowable limit for the majority of distribution systems, all ratings would have to be redesigned. The expense of this would be excessive.

120/208 Volts: Standard transformers will operate satisfactorily at this voltage. The exciting current of a

115-volt transformer, however, is still increased considerably when operated at 120 volts. The effort to reduce the exciting current on distribution systems may make such an increase undesirable. There is also the necessity of allowing for the voltage drop in secondary mains, services and house wiring. Thus, the possibility that a line of 115/120/125-volt transformers would be required is apparent. The cost of such a change in all ratings would be very large. To this expense might be added that of continuing the present standard line of transformers, due to the probability that conditions on the majority of radial systems might make the new ratings unsatisfactory.

115/199 or 110/190 Volts: No changes would be necessary.

6. Miscellaneous Apparatus. This group includes carbon and oil circuit breakers, relays, meters, instruments, voltage regulators, rectifiers, rectigons, fan motors, condensers, and line material.

115/230 Volts, with tolerance of 5 per cent plus, is the existing standard for the majority of this equipment.

125/216 Volts: As 120 volts is now the allowable upper limit for most of the apparatus, much redesign would be necessary, resulting in excessive expenditure.

120/208 Volts: There would be considerable expense connected with changing the design of fan motors and rectifiers for 120 volts, and static condensers for 208 volts.

115/199 Volts: For this voltage the expenditure would be the least. The only change might be a new line of static condensers rated at 199 volts.

110/190 Volts: Some 220-volt apparatus could not operate satisfactorily on 190 volts and there would be considerable expense in redesign and extra stock.

7. Electric Heating Devices. 115/230 volts is the present standard, with allowable variation of 5 per cent plus or minus.

On a combined secondary system the lower voltage heating units are usually connected between the outside conductors and neutral, and balanced among the three phases as often as possible.

125/216 Volts: Since the upper limit would be exceeded at 125 volts, two separate lines of heating devices would very likely have to be maintained, both for industrial and household uses. The expense involved would be excessive and customers moving from one zone to another would undoubtedly experience trouble.

This voltage, if applied to the enormous number of heating appliances now connected on distribution systems, is so much in excess of their present voltage ratings that great trouble could be reasonably expected because of too high temperature or even burnout of elements.

120/208 Volts: There would be a small item of expense to allow for voltage variation up to 5 per cent above 120 volts in connection with a few types of equipment.

115/199 Volts: 115-volt elements are standard.

110/190 Volts: There would be no difficulty with standard apparatus on 110 volts, but it is possible that a new line of 190-volt equipment would have to be developed, with considerable expense attached.

8. Summary for Three-Phase Combined Systems. The fact that 125 volts, the first voltage studied, has not yet been considered a recognized departure from the accepted standard lamp voltage, coupled with the excessive cost to consumers and operating companies for small motors, transformers, miscellaneous apparatus, and heating devices, would seem to weigh heavily against the general adoption of the 125/216-volt scheme.

The 110/190-volt system likewise appears to have serious disadvantages under existing conditions, due to similar excessive expense in connection with general purpose motors, small motors, and motor control equipment.

A summary of the effects of the various three-phase voltage combinations on the different classes of apparatus discussed in the Qualitative Analysis, taking into consideration the total annual sales of each product for the entire industry, was made. It shows large adverse totals against 125/216 volts and 110/190 volts and substantiates the proposition to eliminate those voltages. The summary also indicates a parity between 115/199 volts and 120/208 volts which points to the desirability of studying these two voltages further. This will be done in the Quantitative Analysis.

Effect of Change to Combined Light and Power System for Two-Phase 115/230-Volt Secondary Networks

Similar to the analysis of the three-phase schemes, it is assumed that the two-phase five-wire scheme would be adopted in all areas that could be networked and that in all other systems the present methods of distribution would be maintained.

1. Small Motors. A general adoption of two-phase networks, in addition to the widespread retention of three phase for radial systems, would involve considerable expense due to the production, distribution and maintenance of an increased number of two-phase motors to parallel the line of three-phase motors.

2. General Purpose Motors. As with small motors, the production and stocking of two-phase motors would be greatly increased, with a consequent very large increase in motor costs.

For equal amounts of material, that part which is active in a three-phase motor is practically 6 per cent more effective than in a two-phase motor. All parties would have to share this loss of 6 per cent in the effective use of materials entering into the construction of apparatus.

3. Motor Control Equipment. Due to the use of a grounded neutral in two-phase five-wire combined econdary systems, four overload trip coils may be equired to give full protection, which means the addiion of two coils and rearrangement of all controllers or motors intended for connection to networks. A ourth pole must also be added. The combined ncreased expense in development, manufacture, and stocking would be very large.

4. Safety Switches. A neutral strap and fourth pole must be added where entrance switches will be used on five-wire services; all standard sizes will probably be affected. Four-pole general purpose switches used on lighting feeders may require the addition of a solid neutral connection. Motor starters must have a fourth pole added and it is probable that where thermal cutouts are used two extra cutouts may have to be provided to make a total of four.

The entire extra expenditure would be very large.

5. Transformers. Since the majority of the feeders would eventually be three-phase, transformers would require Scott tap construction. As this calls for interlaced windings, the design is special. If companies not operating networks could see no value in the special design, a separate line for each of these groups would have to be carried in stock. The total extra expense would be very large.

6. Miscellaneous Apparatus. The main changes would be the addition of a fourth pole on certain oil switches and carbon circuit breakers, and the extra cost of two double-pole network protectors or one four-pole protector in the place of a triple-pole protector at each polyphase transformer bank. The expenditure involved would be very large.

7. Electric Heating Devices. The two-phase system uses devices of standard rating.

8. Summary for Two-Phase Combined Systems. The Qualitative Analysis for the two-phase 115/230-volt five-wire combined light and power system thus indicates the possibility of certain disadvantages with regard to small motors, general purpose motors, motor control equipment, safety switches, transformers, and miscellaneous apparatus.

Quantitative Analysis

To make it possible to gage how important these factors may be, and particularly to assist in forming a better conception of the increased cost that might be incurred if any one combination should be adopted for all network systems, requires some form of quantitative analysis.

Table I gives the results of such an analysis. The relative index numbers represent the approximate expense to the entire electrical industry for small motors, general purpose motors, etc., and the totals summarize these expenses for each of the combined schemes considered.

The operating companies that have applied the combined light and power method of secondary distribution have been prompted mainly by the desire to effect a great saving to the entire electrical industry. Table I shows that if any type of combined secondary scheme is generally adopted for networks there will be a heavy expenditure tending to offset some of the gain. It also discloses that failure to standardize immediately will add to this tendency.

Further, it reveals the possibility that there may be a definite difference between the 120/208- and 115/199-volt three-phase systems, in favor of the latter; and that the adverse effect of the two-phase combined scheme may be relatively much greater than that of either of the three-phase combinations.

TABLE X
QUANTITATIVE ANALYSIS
EXPENSE TO ENTIRE INDUSTRY
OVER TEN YEAR TRANSITION PERIOD

Class of apparatus	Three-phase 115/199 volt	Three-phase 120/208 volt	Two-phase 115/230 volt
1. Small motors	19	30	8
2. Gen'l. purpose motors	18	2	26
3. Control equipment	32	32	50
4. Safety switches	5	5	17
5. Transformers	0	21	17
6. Miscellaneous apparatus	1	10	32
7. Electric heating devices	0	0.2*	0
Totals	$75,000,000	$100,000,000	$150,000,000

*Too small to influence total.

Relation of Trends in the Industry to This Problem

If the task of choosing a standard scheme is undertaken, other influences should also be considered in addition to the effect on apparatus existing and required in the future. For instance, what bearing may the numerous trends in the industry have on the contemplated standard? A discussion of a few of these tendencies will serve to illustrate the importance of giving them proper weight.

Trend of Low Voltages

One method often used in gaging which voltages will tend to predominate in low-voltage distribution systems is the analysis of the lamp sales in the voltages of the 100-130-volt class. The curves in Fig. 3, applying to lamps sold during the past nine years, are based on data contained in reports of the National Electric Light Association Lamp Committees. They show one way of determining the probable tendency of system voltages. They give the total annual lamp sales for each of the three main voltages. Up to 1921 the total lamp sales for 120 volts appear to have kept pace with those for 115 volts, with the latter in the lead, but Fig. 3 shows that since 1921 there has been a more rapid upward climb of the 115-volt sales. If the tendencies indicated by these curves become the realities of the future, then it is likely that 115 volts will be the standard for many years to come.

Furthermore, there appears to be little evidence at present of any trend that may change this situation.

Are the companies that are dropping 110 volts adopting 120 volts instead of 115 volts? It is difficult to draw any such conclusion from Fig. 3, for the curves give no indication as to how much of the increase in 115-volt or 120-volt lamp sales is attributable to normal growth of connected load in 115- or 120-volt systems and how much to acquisitions from 110-volt systems.

While the tendency in the past has been towards a steady upward climb of distribution voltage, this seems to have been checked by the approach towards standardization in the last few years. As an illustration, there is the action of a few of the larger syndicates

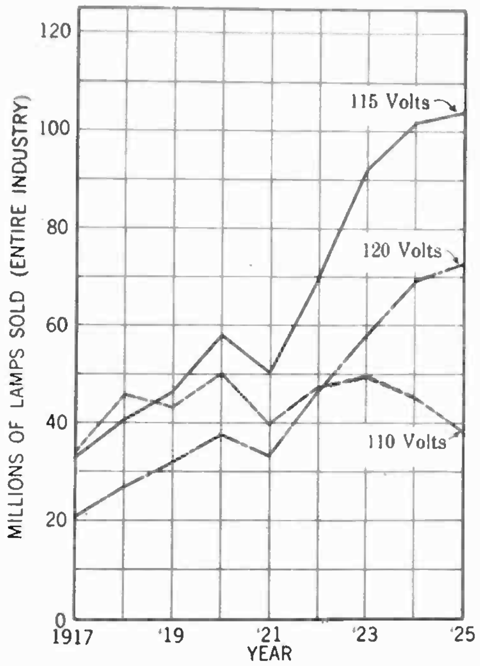

Fig. 5—Total Lamp Sales in Recognized Standard Volt Group

in standardizing on 115 volts for their properties, even though it appeared that the extra capacity available at 120 volts would have resulted in greater return on the investment.

Good Public Relations

The maintenance of good public relations is acknowledged by operating companies as increasingly important. System changes are being made in the manner that disturbs the fewest number of customers. Universal adoption of a standard combined system may inconvenience some consumers at the start regardless of the kind of scheme chosen, but taking into account good public relations calls for minimizing the number thus involved.

The motor users that would be affected by any standard combined system constitute a relatively small part of the entire group of customers. The simple means that have been employed to remedy the motor troubles have been pointed out previously herein. Thus, from the standpoint of good public relations, consideration of the other utilization devices would seem to be of more importance.

Over-Motoring

Many operating companies favor making use of the present degree of over-motoring where possible, yet discourage its continuance into the future. To avoid any injustice to customers who have purposely allowed spare capacity in motors for future increase in loads, these companies stand ready to install the boosting auto-transformers whenever required.

Fig. 4 is the result of a load survey of all the general purpose motors served by a large underground distribution system. Load concentrations averaging 20,000 to 40,000 kv-a. per square mile prevailed. It may be said that the results are fairly typical for most of the underground areas where a-c. networks will be applied.

These curves indicate that in but 10 to 15 per cent of the cases is 100 per cent or more load encountered, and that for the majority of motors and motor h. p. the maximum load is only 50 to 60 per cent of the rating. Examination of the curves of Fig. 2 in the

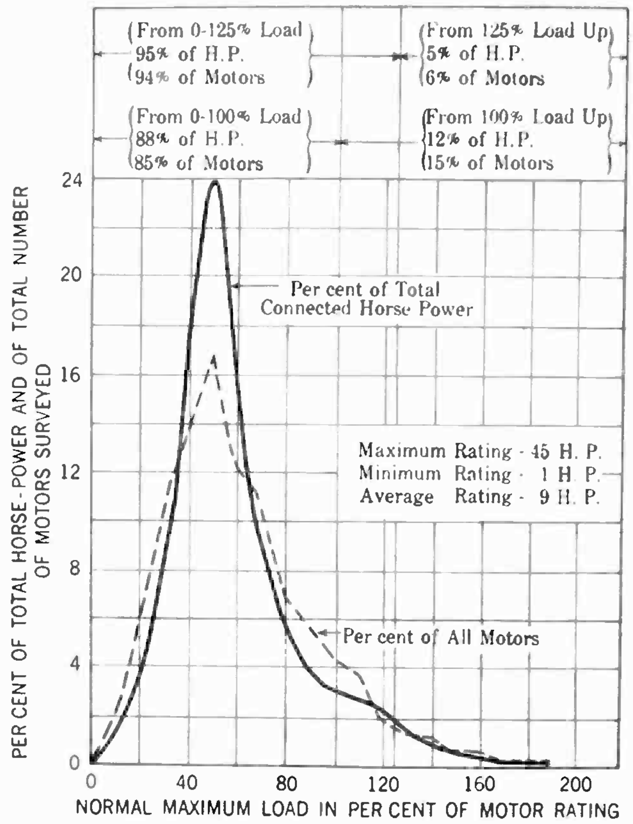

Fig. 6—Load Survey of General Purpose Motors

region of 55 per cent load may therefore be of more significance during the immediate future.

Concluding Suggestions

It is recommended that (a) a standard for combined light and power systems be chosen which fits in best with the most important requirements of the industry as a whole, and (b) if the next best combined system has already received wide application, it be adopted as a recognized departure.

To have a complete study of these requirements made as promptly as the importance of the problem merits and to allocate to each its proper relative weight will require the concerted attention of the electrical operating companies. Nor can the manufacturing companies hope to avoid their proper share of any task that may arise as the result of a decision based upon that study. The full cooperation of both branches of the industry will be necessary to arrive at a solution involving the least burden to all concerned.

The following are a few suggestions for action whereby this purpose may be accomplished.

The active interest of the leading men in the industry should be enlisted. Their long experience with such problems and their intimate knowledge of the losses due to lack of prompt action in the past should be brought to bear.

An intensive effort to improve the design of combined light and power systems for networks, in order to eliminate compromise as far as possible, would be of distinct value.

Cooperative effort will be needed to encourage the active support of any agreement on the part of all operating companies. A conservative campaign of education on the value of adopting one standard for combined secondary systems would decidedly aid this effort.

The manufacturing companies should make sure that none of their policies tend to promote the use of such schemes and voltages for combined light and power secondary systems as may differ from the standard that will be chosen.

Discussion at Annual Convention

GROUND-RELAY PROTECTION FOR TRANSMISSION SYSTEMS[1]

(Jones and Dodds)

DIRECTIONAL GROUND-RELAY PROTECTION[2]

(Breisky, King, and North)

Detroit, Mich. June 21, 1927

H. P. Sleeper: I was not aware that we had progressed to the extent indicated by Mr. Breisky's paper, where we can actually place ground protection on a system where there is no ground current.

However, the method described by Mr. Jones in his paper is one which I believe indicates a distinct advance in the art. Perhaps five or six years ago it was a hard proposition to sell to operating engineers the idea of ground protection. At that time short-circuit protection was pretty much standardized, and they saw no necessity for complicating the situation.

However, today that is not the case, and I believe that ground protection is fully justified for two reasons in particular. In the first place, ground-relay protection will tend to minimize the damage at the point of fault. On the system with which I am identified, that of the Public Service Electric and Gas Company of New Jersey, we have several hundred installations of the type of ground-relay protection described by Mr. Jones. We are operating a 26-kv. system with 75 ohms in the neutral. This limits the current to ground to 200 amperes, high voltage. We find that its operation is extremely successful.

To illustrate the limiting of the damage at the point of fault, an example is a case which occurred recently when a ground was found at the joint of a 26-kv. cable. The line tripped out at both ends, and finally, by tests, the fault was located in the joint. The joint presented no external appearance of any abnormal condition within. The sheath was not enlarged nor blown apart, and there was no hole through it. The joint was opened, and there was a little hole through the compound, possibly as large as the end of one's little finger, showing where the current had gone to the sheath without burning through. On the conductor there was an extremely small amount of burning; so little that the joint was very easily re-made and re-insulated without the necessity of any additional line conductor being added.

The second effect, which really is an indirect one of the first result, is that of reducing the distress on the system. Prior to the installation of the 75-ohm resistor, we used the solid neutral on this system. A wire falling to the ground would give a severe voltage disturbance to the system, a 10 or 20 per cent dip being not uncommon during the trouble.

Now, a successful operation of the ground relays gives from 2 to 4 per cent voltage dip at the ends of the line which is not discernible on lights. I believe that this is very essential to the satisfaction of customers.

Another point that I should like to mention in connection with ground protection, is what I believe to be the necessity of making research faults on the system. I have made quite a few of such high-voltage grounds on the lines while investigating the efficiency of ground-relay protection, and in most cases to say the least I have found that the executives of the company were not heartily enthusiastic about the idea of making these faults. I believe that a certain amount of such testing is necessary as a research proposition.

That brings me to the third point which I would like to mention; namely, the methods of testing ground relays, to be certain they are properly connected and will operate correctly.

Mr. Jones has described the use of a phantom load, the use of the line load, and the actually making of faults on the high-voltage system, to check the ground relays. I have never been able to find a successful system of using phantom loads to do this. However, I find that the use of line load and line voltage can be used very successfully to check these relays.

We have devised a method of short-circuiting one current transformer while the line is carrying the load, and of opening one high-voltage disconnect switch without in any way disturbing the connections to the high-voltage system. With this method it is possible to obtain a set of phasing results on directional ground relays, which, to date, has given us no incorrect operations. I do not believe that the actual grounding of the high-voltage system is necessary.

I should like to say a word regarding Mr. Breisky's paper on the ground protection of isolated-neutral systems. As I understand the situation, the relay which has been developed to do this job is essentially the same relay that Mr. Jones has described wherein the system is actually grounded, the difference being that the relay on the isolated-neutral system uses charging current to operate it, and hence, different voltage relations result on the relay protection.

I should like to ask Mr. Breisky if it is not possible to use the same relay for both applications, thereby greatly simplifying a problem which is a difficult one for us right now. We have a system which has a neutral resistor at one station. If for any reason that one resistor must be removed from service, it becomes necessary or desirable to ground the system at some other point.

1. A. I. E. E. Journal, October, 1927, p. 1080.
2. A. I. E. E. Journal, November, 1927, p. 1184.

We have one system which has no duplicate resistor; therefore, the problem arose, shall we dead-ground the system or leave it ungrounded during the time the resistor is out? We tried dead-grounding the system but it was an unsatisfactory experience, for we found our ground-relay system worked backwards. I am referring to the ground relays which were tested to operate correctly with the 75-ohm resistor in the neutral. Hence our running orders are to leave the resistors isolated while the resistor is out. This we do not consider satisfactory. It occurs to me that possibly some method of external use of resistors and reactors would make it possible to use the same relay under all these conditions.

H. M. Trueblood: I have been interested in the two papers on ground relaying from a standpoint of which I think no mention has been made by the authors of either paper: I refer to the question of the control of inductive disturbances in exposed communication circuits at times of faults to ground in power systems. This in my judgment is one of the most important questions that we have in the field of inductive coordination.

Without desiring to enter upon any discussion of the relative merits and disadvantages of the various means that have been used or proposed for establishing and maintaining a relationship between a power system and the ground, I would like merely to say that it is an interesting thing that in the paper by Mr. Jones and Mr. Dodds, a reason is given for which a certain amount of resistance in the neutral ground connection is beneficial from the power operating standpoint. In the subsequent discussion of that paper, we have heard statements to the effect that from the standpoint of power operation, such resistance is advantageous for two other reasons, limitation of damage at the point of fault and lowering of stresses on equipment.

We can take it for granted, I think, that so far as inductive coordination is concerned, the limitation of ground-fault current is desirable, and it is very agreeable and satisfactory to note that good reasons also exist for which such limitation is desirable from the standpoint of power system operation.

It would be interesting to know whether data exist, and if so, what they show regarding the optimum value of resistance from the standpoint of ground-relay operation. It would seem from the paper by Mr. Jones and Mr. Dodds that beginning with zero neutral resistance, a rapid increase in the wattage available for relay operation will at first be realized as the neutral resistance is increased, and that as further increases are made in resistance, the benefit will accrue less rapidly. This has been pointed out to me by Mr. A. E. Bowen, who has also noted that if the resistance is increased beyond a certain value, the wattage for relaying would probably decrease. It seems probable that there will generally be a considerable range of magnitude of neutral resistance over which the watts available for relay operation would be favorable, and not greatly dependent upon the magnitude of the resistance.

E. E. George: Our operating experiences on the Tennessee Electric Power Company system confirm a good many of the recommendations suggested by the Duquesne Light Engineers, but there are several points of difference,—some of which are undoubtedly due to different operating conditions.

Our system operates with solidly grounded neutrals at all generating stations, all substations which can supply power outward, and at a few receiving stations. The size of grounding transformers on the 120,000-volt system ranges from 7500 kv-a. to 50,000 kv-a. and from 200 kv-a. to 25,000 kv-a. on the 44,000-volt system.

We are very certain that directional ground relays are absolutely necessary on our high-voltage transmission system, more especially since our parallel balanced lines are very few, and since trunk tie lines with other companies without isolating transformers are becoming more common.

However, our scheme of directional ground relaying is different from the scheme outlined this morning, and is, we think, simpler, and more reliable, at least for systems which have transformers suitable for grounded-neutral operation at practically all switching points. We are using directional ground relays operated by two currents instead of by a current and potential. One current element of the relay is supplied from the neutral or residual of the bushing current transformers in the line to be protected, and the other element is supplied from a current transformer in the neutral ground lead of the grounding bank. We formerly used relays which had separate over-current and directional elements with the directional disk operated by the two currents and the overload disk operated by one current. We are now using relays which have the over-current and directional elements combined in one disk.

Very probably all reverse power or directional ground relays on our system installed hereafter will have only one common disk, as we have found that relays with separate over-current and directional elements are likely to trip incorrectly due to surges which will close the instantaneous directional element regardless of fault location after the overload element has closed.

We have no objection to the system of protection outlined by Mr. Jones and Mr. Dodds and expect to use it at any point where we are unable to secure grounding transformers, since the installation of star-delta high-voltage transformers will undoubtedly be cheaper than buying a grounding bank in most cases.

We have had very poor success with ground relays interlocked with reverse power relays. We have only one such installation and it will be removed this year. We have had some sad experiences with this scheme on tie lines where there is a possibility of surging of power or reactive kv-a. during trouble. We have had reverse power relays on both sides of a large load center set to trip outward, drop the load during trouble that should have operated neither relay. We have also had a large number of cases where the power load was heavier than the ground current and the reverse power relays could not operate. Even with heavy grounding transformers we find that ground currents are often less than load currents and ground protection independent of load protection is absolutely essential.

The application of reverse power relays on large transmission systems is apparently very limited. We find that the reversal of power is an infrequent indication of trouble and often occurs during abnormal operating conditions, and we have eliminated all reverse power relays on this system, except at two stations.

We have had very satisfactory operation with balanced ground relays after we learned to interlock them through "A" switches on the breakers so that the second line could not trip immediately after the first line, except by back-up over-current ground relay.

We are absolutely in accord with the Duquesne Light Company on the necessity of placing grounds on the system to test out important relay installations. We have not standardized the equipment or procedure of this as we have only made five such tests to date, but on four cases we have solidly grounded the line with reduced generation on the system and read the ground current at a station distant from the point of grounding. On a long line between the grounding transformer and the artificial ground, the ground current is limited so that it can be left on long enough to take meter readings without damaging power equipment or interfering with the public telephone and telegraph circuits.

H. A. P. Langstaff: One advantage of the ground relay which has not as yet been mentioned is the reduction in duty on oil circuit breakers. The West Penn System, like all others, had breakers which were unable to withstand the duty to which they would be subjected unless some modifications were made, and the ground relay along with the neutral resistor was of considerable advantage. When relays were originally applied, we used overhead ground wires on all 25-kv. circuits, and the majority of line failures were to ground, meaning a large percentage to ground-relay operation. The installation of higher capacity breakers and the removal of overhead ground wires has shifted the percentage of failures to phase relays rather than ground relays.

The clearing of faults by means of the ground relay materially reduced system voltage disturbance. We have replaced the watt-relay by the directional relay, having two separate elements,—namely, the current element and directional element,—thereby allowing all ground relays to have the same characteristics and simplified settings.

Another point which has not been mentioned is the protection supplied for reserve bus breakers. All operating companies experience line failures when lines are operating on reserve bus breakers, thereby removing from service the balanced relaying schemes. This, of course, subjects the system to greater disturbances due to higher settings, and I believe that this should receive serious consideration by all operating companies.

As to the checking of ground relays, we used originally a phantom load for the watt-relay. Then we started to apply grounds to the system to check the selectivity of the watt-relay against current relays. After changing to relays of similar characteristics, we continued the ground application scheme of checking, but found that the phantom-load scheme was satisfactory, especially when we use the scheme mentioned by Mr. Sleeper, namely, diverting phase currents having known direction through the ground relay, and opening one leg of the potential transformers. Our field testing crews are obtaining very reliable results from this scheme of testing and the only time we apply the ground is after an occasional faulty operation to check not only the ground relays but phase relays as well, in some cases.

G. H. Doan: I realize that there is a vast difference between the protection of a resistance-grounded system and that of a solidly grounded one. I should like to point out the scheme, however, that the Detroit Edison Company is using. In general, we have used for a number of years on all transmission lines,—120-kv. and 24-kv.,—a mechanically balanced differential relay. The operating experience with this for the past year has been in results, somewhere in the neighborhood of 98 and 99 per cent perfect.

This system is very advantageous, we think, in that it is almost instantaneous. Objection has been raised to the reduction of voltage at the time of fault. We realize that we do get voltage reduction at the time of fault, but we have found that if we can clear a fault quickly, we don't need to worry about the reduction. This relay has been doing it for some time.

Mention was made of low-energy relays. Again, we are different in that we believe that most of the relays furnished are not nearly sturdy enough and don't take nearly power enough, nor have sufficient force always to operate when you want them.

Manifestly, with a large system which is rather compact, it is rather difficult for us to see how we could go out and ground our lines for checking relays. As a matter of fact, I believe that our present check, made through the use of portable test transformers, (putting primary current through the current transformers as a current-transformer check and carefully tracing the potential-transformer circuits to the relays, added to a check on the relays as they are put into service to make sure that they are going in the right direction), has, so far, resulted in practically perfect connections. I cannot recall a single case of error of relay connections in the last two years. Unfortunately, we have had one or two cases of incorrect relay settings.

L. N. Crichton: The question has been raised as to the operation of ground relays on a system having its neutral dead-grounded.

The relay connection under consideration is the conventional one using a wattmeter type of relay, connected in the delta circuit of a bank of star-delta potential transformers. It happens that the voltage actually applied to the relay is the drop between the relay and the source of power, and consequently the phase relation between the current and voltage depends upon the characteristics of the power supply rather than the characteristics of the trouble.

When you take the resistance out of the neutral, the current lags far behind the voltage, and in addition, you get distorted phase relations due to unbalance in the voltage triangle, resulting in the current lagging more than 90 deg.; actual tests on a system showed 92 deg. Then, if you take into account other errors that are likely to creep in—unbalancing of potential transformers, and so on,—you will see that the relay has a poor chance of working correctly, if it is a true wattmeter. The trouble can be taken care of by making a relay which will work more efficiently on lagging current, and such a relay has recently been developed.

The question of removing the resistance from a number of systems is now under consideration and on these installations, the present relays can be kept in service by putting small phase-shifting devices on them.

The type of relay having its greatest torque with lagging current should be used, in general, on all systems, even those having a high resistance in the neutral, so that the installation will not require change if it should later be decided to remove the resistance.

J. Allen Johnson: (communicated after adjournment) I do not think that Messrs. Jones and Dodds intended to convey the impression that the use of "power relays with self-contained timing element" may not be entirely successful and satisfactory under some conditions, but such an impression may be created by their statement in the last paragraph of the first column on the second page of their paper.

The Niagara Falls Power Company has had in successful operation for several years on its 66-kv. circuits a system of ground protection using a specially designed low-energy power relay. The conditions here are very difficult as the neutral ground resistance may be as high as 750 ohms and the current transformers which supply current to the relays have a 600/5 ratio. Thus the ground-fault current may be as low as about 50 amperes, which may be divided over two parallel circuits, giving only about 25 amperes primary current in the current transformer or slightly over 0.2 ampere relay current.

The relays were designed to operate with 0.15 ampere with full voltage on the potential coil. Voltage for the relays is obtained from a potential transformer having a ratio of 34,500/115 connected directly across the 750-ohm neutral resistor. On account of the high neutral resistance, a very large proportion of the fault voltage always appears across the neutral resistance and potential transformer, and this resistance being practically non-inductive, the voltage is always nearly in phase with the fault current. This results in very positive relay action.

The excellent operating record of this installation during the 3½ years of its service is shown by the following record of operations.

	Ground relay operations on 66-kv. system			
	Correct	Desired	Incorrect	Undesired
1924	28	28	0	0
1925	28	28	0	0
1926	11	11	0	0
1927 (to June 25)	2	2	0	0
Totals	69	69	0	0

V. P. Brodsky: (communicated after adjournment) I should like to ask a question regarding the use and interpretation of the vector diagrams illustrating this paper. Subtractive-polarity current and potential transformers are used in the connection diagrams given in the paper. This may be seen from the polarity marks on these diagrams, and is also in accordance with the present standards.

In a subtractive-polarity transformer the primary (impressed) voltage is opposed in the internal circuit by the secondary (induced) e. m. f. This also applies to the currents.

However, in the external circuit, a subtractive-polarity transformer does not introduce a change in polarity, which remains the same as if the transformers were not existing. It is therefore the reversed secondary voltage or reversed secondary currrent delivered to the relays which should be made use of in these applications.

I notice that in the vector diagrams given in the paper, the primary current is opposed by the secondary current, and the primary voltage by the secondary voltage.

I should like to ask whether the writers have considered the internal circuit of the transformers or the external circuit.

B. M. Jones: Mr. Sleeper asked about the use of the same relay for solidly grounded or resistor-grounded systems. I understand that one manufacturer has actually developed internal additions to present ground relays to cover just that field. This worried us considerably, too, as we contemplated grounding solid.

We very strongly favor actually grounding the systems for testing the directional ground relays. We have just finished the program of applying 305 grounds on our 22-kv. system to check 484 relays and found 17 field errors which our best inspectors couldn't find by any phantom method.

We have also finished a program of grounding our 66-kv. system to test the ground relays and found six incorrectly connected. We start about midnight and finish about four or five in the morning; we make 35 or 40 grounds a night. We have the relay testers scattered over the system. It isn't very expensive and we feel that the expense is justified.

Mr. Johnson is right in assuming that the authors did not intend to convey the impression that the use of power relays with self-contained timing elements might not be entirely successful and satisfactory under some conditions. The statement made was that "the power relays have not proved satisfactory for ground protection due, primarily, to the fact that a sufficiently low-range relay has not been used."

The relay described by Mr. Johnson and used on the Niagara Falls Power Company System, operates on a very small number of watts, and, as Mr. Johnson points out, the conditions on their system and their source of voltage for the relay are such that the voltage impressed on the relay under fault conditions is of a fairly high value; also, this voltage must be very nearly in phase with the fault current, thus insuring positive action of the relay.

The Niagara Falls Power Company's solution of its problem was very good, but this solution is not open to a great many power companies since many companies do not have ground connections at a large number of their stations.

As Mr. George of the Tennessee Electric Power Company points out, a great many of the points of difference are due to different operating conditions of various power companies. The scheme used by the Tennessee Company of getting its directional ground protection by the relative directions of two currents in the relay, one current being obtained from the line protected by the relay and the other from the grounded neutral of the power transformer bank, is a very cheap method of obtaining directional ground protection.

Again, however, this method is limited to those companies having their transmission systems grounded at their substations.

In regard to Mr. Brodsky's question as to whether the vector diagrams shown in the paper had reference to the internal circuit of the transformers or the external circuit, the vector diagrams, themselves, show only the phase relation existing between the current and potential on the relays, while the arrows in the relays indicate the instantaneous directions of the currents and voltages at a given time. For example, suppose we take the instant of time when a phase voltage is at a maximum, and assume that current is flowing out on the high-voltage line in the direction indicated by the arrows from the oil circuit breaker. Then, due to the subtractive polarity of the current transformer, the direction of current in the A-phase relay would be as indicated by the arrow. However, the voltage applied to this relay is the voltage from A-phase to C-phase, and since the instant of time was assumed when a phase voltage was at a maximum, then the C voltage would be at about half maximum value, and A-phase, being at a higher potential than C-phase, the direction of potential would be from A to C in the external circuit.

The arrows and direction in the other two relays are also taken at the instant of time when that particular phase voltage is at its maximum value.

J. V. Breisky: Mr. Sleeper has asked whether the same relays could be used on systems grounded through resistance as on ungrounded systems? This can be done by somewhat changing the phase relations in the present design of relay, either by making changes internally or by means of external resistors and reactors as suggested by Mr. Sleeper. A relay could probably be developed which could be used interchangeably on these two types of systems since the limits of the phase position of the ground currents on both kinds of systems are quite well fixed. Of course this relay can be used on the ungrounded system only if the residual charging current is of sufficient magnitude to operate the relays as designed at present. It would be more satisfactory probably to dead-ground the system when it is necessary to remove the resistor and use a phase shifter to give correct operation (as mentioned by Mr. Crichton) with the present relay, which is designed to operate on systems grounded through resistance.

As pointed out by Mr. George, it is possible on systems grounded at every substation, through power or grounding transformers, to secure good ground protection by using relays operating on the product of the current through the transformer neutral and the line residual current. In this case, most of the ground current is supplied by the transformers adjacent to the grounded section and the relays may be operated on the inverse part of their curve to get good discrimination between the various sections. Such a relay is also directional, since the current through the transformer neutral always has the same direction, and it takes the place of voltage in serving as the reference quantity. Relays of this type have been used on the Pacific Coast with good success for several years and are being installed on several new jobs.

Certain types of over-current relays have slow-opening contacts. If, however, the fast-opening type is used with the directional contacts correctly spaced, I feel that the trouble mentioned by Mr. George, that of improper operations caused by closing of directional contact after over-current contacts have closed, will not be experienced. This could happen only after a breaker had opened, clearing a fault, and the flow of power had changed due to the distribution of load. If the over-current contacts are of the quick-opening type, they will be open by the time the directional elements close and the breaker will not operate. If for any reason the direction of power flow should change after a fault has occurred on a system and before it is removed, relays with a single element as well as those with separate over-current and directional elements would operate.

The trouble mentioned by Mr. George, of a load current of greater magnitude than the ground current preventing the reverse-power relay from operating correctly, can occur only when a non-directional ground relay is interlocked with directional elements operated by line current and voltage. The scheme outlined by Messrs. Jones and Dodds used when the system is solidly grounded with a suitable phase-shifting device as mentioned by Mr. Crichton, in which the relay is operated by residual current and voltage, is entirely independent of load currents.

Mr. George's statements that "the application of reverse-power relays on large transmission systems is apparently very limited and that reversal of power is an infrequent indication of trouble" are not quite clear to me. The reversal of power accompanied by an abnormal current is certainly an indication of trouble, and reversals unaccompanied by over-current will not cause operation of relays. There are thousands of relays of this type giving satisfactory service and in many cases it is the only type which will give the necessary protection.

The scheme of using mechanically balanced relays, as mentioned by Mr. Doan, is, in general, very satisfactory except that its use is limited to cases where there are enough lines in parallel so that there will always be at least two left under any operating condition. Such cases are not common except in large urban cable systems. Undoubtedly, as Mr. Doan points out, it would be desirable to use relays which would take more power to operate but which would be more positive in their operation. Unfortunately, however, the demand seems to be for a relay that will require less and less power to operate it except possibly on large cable systems where a large amount of power is concentrated into a relatively small area. So far as sturdiness is concerned, however, we seldom hear of the mechanical failure of a relay.

In answer to Mr. Brodsky's question regarding the vector diagrams, I should like to mention that it does not matter whether the secondary quantities are shown reversed or not, since this will affect both current and voltage similarly and the phase relations will remain unchanged. Although vector diagrams are not entirely standardized, I believe the line quantities and the relay quantities are usually drawn in the same direction when subtractive polarity transformers are used since this is in line with the idea that the transformers may be considered as straight-through connections.

REPORT OF COMMITTEE ON RESEARCH[1]

(WHITEHEAD)

DETROIT, MICH., JUNE 22, 1927

F. C. Caldwell: There are two types of minds that are particularly adapted to the training for research,—on the one hand, the student who is distinctively scientific, who has the real research spirit, the desire to know, the scientific curiosity,—on the other hand, the inventor, the man who has ideas that seem, to him at least, to be inventions of importance.

The man of the first type is interested only moderately in the money side of his work. The man of the second type usually has in mind that financial return his invention will bring to him and often vastly over-estimates its money value.

Such a student needs to have impressed upon him the real situation with regard to invention and development, the problems and the difficulties involved and the value of team work in this connection. He may thus come to appreciate the advantage of working cooperatively in an organization rather than trying to play a lone hand.

The other student, the one who is of the scientific research type, wants to know that he will earn a good living, assuming a reasonable degree of success, and that he will not have to worry too much about the cost of living, if he trains himself for and devotes himself to research.

Recently one of the large electrical organizations sent us a curve showing the average salaries which the graduates of our institution were earning at various intervals after leaving college It was a very interesting curve, and quite encouraging. It showed that for a man who was satisfied with a comfortable living, that was a good organization to join; little prospect of making a fortune, but an opportunity to live a comfortable life.

It would be interesting if we could have such a curve for research workers. A curve like this, if it shows such an upward slope as I believe it will, should be very encouraging to would-be research workers.

Another point,—often when a university teacher does develop some research ability, he is taken out of teaching work and absorbed by industry. That is a real difficulty, but we certainly would not want to eliminate it. The loss of such men from education is a hard problem to solve. Perhaps there is no solution for it, until the time comes, if it ever does, when teachers will be paid salaries commensurate with those that the same men get in industry.

R. W. Sorensen: The educational problem in our engineering colleges up to the present time has been largely with undergraduate students whose college life is limited to four years. A few engineering colleges are extending their courses to five and in some instances to six years. This seems to indicate that in the near future there will be available in the colleges graduate students who will have the required preparation and time to do research work.

Just at present the scientists are ahead of the engineering students in their ability to raise finances for pure research work as compared to applied research work or engineering research work.

In those colleges with which I am acquainted a pure scientist research teacher may have one course to teach, and usually that is just a lecture course, or perhaps he has only a few research men with whom he holds conference regarding their research problems. Engineering teachers for the most part have to devote about half their time to teaching; some of them also have to devote a large share of time to administrative work to keep a department going, in addition to being expected to try to get in a bit of personal research work and at the same time inspire students' work of a research type.

In engineering as well as in pure science we must find a way to make available a large number of fellowships which capable men may make use of while doing research work and studying for a Ph. D. degree in engineering. At the present time the few available fellowships of this nature make it necessary for engineering students who are not members of fairly well-to-do families to find all kinds of outside work in order that a few dollars may be earned to keep soul and body together.

Another factor is, only a few of the industries of today have expressed a willingness to pay for increased engineering training beyond that required to obtain a Bachelor's degree. I think it can well be said the few who have been liberal in paying men who have been worthy of doing graduate work have found the increased pay a profitable investment. Another factor is that engineering research men have been directed toward commercial problems because of larger pay frequently given to commercial men.

If colleges are to undertake engineering research problems they must also give considerable attention to the study of patents, how to obtain them, and the ownership of patents resulting from research work in college laboratories. It is my opinion that for the best results, patents thus developed should be the property of the educational institution where the work is done, but the institution must, on the other hand, do as the industries have done, recognize patentable features resulting from research work as worthy of being the basis for financial compensation to the workers who make it possible to obtain patents. Inasmuch as educational institutions have limited funds available for taking out patents, industries, who after all will get the return by manufacturing the goods, must be very liberal in assisting the educational institutions in developing and patenting new devices.

In fact, the whole problem is intricate and requires a great deal of study, but that study is inevitable because our technical problems are reaching a state where they can be analyzed and extended further only by engineers who have a thorough understanding of modern physics and mathematics; that is, the engineering profession has become so thoroughly a language of physics and mathematics that four years of training is insufficient for the man who wishes to be in the forefront of technical progress. To make it possible for colleges to turn out such men the industries and colleges must work out a new plan for financing men qualified to do graduate work. The colleges must see to it that they admit to graduate work only men peculiarly fitted for it.

Some criticism has been made regarding the number of papers coming from our college research laboratories. I am quite con-

1. A. I. E. E. JOURNAL, December, 1927, p. 1338.

vinced, however, that the colleges are producing results commensurate with the amount of money spent in their laboratories equal to that in the industrial laboratories. Our own experience has been such as to indicate that often research problems useful to industries can be carried on by students in a college laboratory as well as by a man in an industrial laboratory for much less money than the industry would require should they use the same man for the same work in one of their own laboratories.

R. E. Hellmund: I think the subject of research in colleges is a very timely one to discuss. The reason why I believe so is that there are relatively few students coming from the colleges with the intention of taking up research work or design work which is similar to research. I have for many years interviewed most of the students coming to the Westinghouse Company to take up engineering work, and until recently the large majority of them showed a preference for application work and but very few came with the idea of going into design or research.

We, of course, have given this a good deal of thought, because a manufacturing company is primarily in need of design engineers. The usual idea that the compensation may be the reason for the existing condition can hardly apply because the salaries of research and design engineers are in general the same as those of application engineers. I believe the real reason is that the colleges do not instill into the students a desire to do this kind of work. I have found, for instance, that in some schools the students during their senior year do a number of design calculations for induction motors, generators, transformers, etc. They are given formulas for this purpose, and in using them make numerous mistakes. Because of their inexperience, they do not discover such mistakes until well toward the end of their calculations, and as a consequence they are obliged to carry through the slide-rule work many times. As a matter of course, they become thoroughly disgusted with the work and make up their minds that this is not the kind of thing they wish to do all their lives.

With the realization by the schools that it is impossible to give the students a complete knowledge of design, there has for several years been a tendency to eliminate design activities entirely and merely equip the students with a fundamental knowledge. This point of view has also found support with the representatives of the industries, who felt that if the student had a thorough knowledge of fundamentals, the industry could teach him the particular design knowledge required. This may be true, but it must not be overlooked that even the fundamental knowledge is merely a tool and that the real function of the research man and the designer is to create. In other words, all the fundamental knowledge is of no use if the design engineer does not have the desire and ability to create, and I therefore do not believe it is safe to keep a student in college for four years merely absorbing knowledge and without continually fostering in him the desire to create something himself. Unless this is done, the student is not properly developed for his future work, nor will he be interested in design or research work upon entering industry.

It is, of course, impossible to teach all varieties of design and research during the limited time of a college course. However, I consider it essential to keep the student engaged in some kind of design work throughout the entire course, without any attempt to cover the entire field. Starting with the simplest kind of problems, more difficult ones may follow later, and care should be taken at all times to utilize and apply in this connection the knowledge acquired in the fundamental studies.

I fully agree with the previous discussors that additional financial resources are desirable in connection with the research work of the schools, but I also believe that a great deal can be accomplished simply by keeping the student interested in design and research work and continually fostering in him a desire to exercise his creative ability.

W. A. Del Mar: There is one observation I would like to make about training of research men which I believe, has never come up in the discussion between the engineers and educators; that is, the importance of training men in manual dexterity, both for making instruments and experimental "set-ups," and for their manipulation.

Success in research work depends very largely upon the dexterity of the worker in making, assembling, and using apparatus. The man who depends entirely upon ready-made commercial instruments or who has to wait for the commercial concerns to make his instruments will not get very far in research work.

There is one other point in connection with training of research men, and the development of research mentality. I do not think there is a single research mentality. We need two different types of men in the research laboratory, one having reliability in making measurements, and the other having extraordinary coordinating power, bringing together the results of tests and uniting them together into something new. I think those are two entirely distinct types and ought to be recognized as such by the educators.

J. Tykocinski-Tykociner: (communicated after adjournment) Research becomes more and more the result of cooperation instead of the effort of a single individual. With the growing complexity of engineering problems, the number of individuals participating in the solution of a particular problem will naturally increase. This development, conspicuous in the industrial laboratory, will have to be met also in the colleges. The development of theory, experiment, and equipment forms the three special divisions of research activities in which the individual research workers will have to specialize according to their natural aptitude. The type of student gifted in theoretical formulation of problems finds ample opportunities of preparing himself and developing for research work. Originality and knowledge of mathematical methods is all that is required for his future success.

However, the gifted experimenter, whose chief aim is to apply his creative faculties to the development of new methods of investigation, the design of new apparatus, and to the surmounting of innumerable difficulties presenting themselves in the course of research work, finds himself limited by the lack of talent to do things requiring skilled manual work. An inventor of new scientific methods and devices will rarely be sufficiently skilled in mechanics to produce the actual experimental apparatus and precise measuring instruments he requires. In fact he will find in most cases that there is no mechanic available at the college who could do all the work he needs. If he can get the mechanic to do work on his apparatus, he will find him a dutiful craftsman but without initiative or understanding of the real needs for which the apparatus is to be built. Colleges as well as industries must face the fact that the old generation of good mechanics adapted for the varied auxiliary research work is vanishing and that the present sources for supplying trained men are inadequate. Continued progress in research calls for the creation of an efficient professional body of mechanics especially trained for research work. The research mechanic of the immediate future will regard his vocation as a fine art and he will acquire all the knowledge, training, and skill in a special department of an engineering school to be created for this purpose. The research mechanic will actively cooperate with the theoretical investigator and with the experimenter. His aim will be to produce and to improve the equipment required for the solution of the various problems. All three must have an understanding for one another's part of the common work. The work of each must be regarded as an equivalent contribution. Each of them will participate with his particular ingenuities for a common achievement. Cooperation of this kind and the organization of special courses for education and training research mechanics seem to me to be the factors which will further research and which should be stimulated at the present stage of development.

PAPERS ON OVERHEAD CONTACT SYSTEMS

(Viele[1], Brown[2], Thorp[3], Wade and Linebaugh[4], and Jorstad[5])

Detroit, Mich., June 24, 1927

H. F. Brown: Mr. Viele's paper emphasizes many points which are in line with similar experience on the New Haven system such as

1. The advantage of the auxiliary wire above the working conductor.
2. The necessity for proper steadying devices for the trolley, on both tangent and curve construction, especially against transverse wind loads.
3. The avoidance of long spans in exposed locations.
4. The advantage of locating sectionalizing and splicing devices at or near the supports.
5. The avoidance of hanger members which do not make a positive contact with both the messenger and the contact.
6. The importance of correlating the pantograph design with that of the overhead contact system, and the possibility and desirability of further refinement in the pantograph design.

In connection with the tests described, it would be of interest to know what effect the tensions of the auxiliary and the contact have on the amplitude of movement at the support point. Lower tensions, especially of the auxiliary, might offer an improvement. It would also be of interest to know the effect of the contact-wire tension on the speed at which the oscillations travel along the wire; also a comparison of the effect of the very light rods now being used on the newer installations, as compared with the columnar effects of the older, heavier types.

M. W. Manz: The amount of rise of the pantograph wire in any catenary span would be in proportion to the unloading or in proportion to the pantograph pressure. That can be laid out rather accurately with the force polygon, and if one follows the movement of the pantograph through a number of locations one gets an unloading diagram similar to the curve Mr. Viele has presented.

There is a rather peculiar thing about that type of diagram; the movement of the system is the largest at the center of the span. Has any thought been given to the possibility of increasing the weight of the system at the center of the span as opposed to increasing it near the supports which now happens due to the longer hangers? In other words, if you take the diagram and unload it at various points, you will find that an unloading at the support has much less effect on the system than at the center of the span. Has any consideration been given to the possibility of some correction, perhaps, for the unloading at the center as opposed to more unloading at the supports?

In connection with the long wave motion, which you have with a number of pantographs in a span, with a number of spans there is a rather interesting combination. Has any observation been made as to the extent of movement of the suspension insulator? When you unload a span, you reduce the tension. When you do that, the insulator will swing, giving an effect of balancing the tension back through the system. There might be another interesting point to consider for future investigations; can the loadings of the messenger be decreased as you approach the supports in such a way that the lift of the system is uniform?

G. I. Wright: We on the Illinois Central are considering the application of roller bearings to our pantographs—something that has not been done generally in this country, but I believe has been done abroad.

In both Mr. Viele's and Mr. Brown's papers, they mentioned a provision that they thought necessary to make for flashover of insulators—burning the construction and so on. I might say that due to the system we use and the design of it, we have had no flashover of insulators and practically no burning of wires. The only burning of wires we have had, except that caused by a direct stroke of lightning, has been the burning of the contact wire where the pantograph ran from a live section to a dead section on which there were a large number of trains standing. In leaving the gap, this caused an arc which was maintained, and burned the wires.

I might state that in order to prevent this burning we are installing dead-section signals which will stop a train from passing from a live to a dead section.

The fine results due to the elimination of burning and arcing are also largely due to the high-speed breaker protection we have on all feeders energizing the catenary.

In Mr. Jorstad's article, I thought possibly he gave a wrong picture of the popularity of the inclined catenary. I believe that both types have their use and their field, and that certainly the chord construction is better for a great many installations, particularly where there are few curves and considerable copper is required.

Mr. Jorstad listed eleven railroads which use inclined catenary, and stated that this indicated that this would be a future standard overhead. There are very many important railroads which use the chord construction.

Mr. Jorstad also said that in using inclined catenary only two wires were necessary whereas with chord construction three or four are used. I believe that is limited to short-span lifting-hanger construction, while two wires would not be feasible for long-span construction generally used for heavy electrifications.

Apparently, Mr. Jorstad's method of design greatly simplifies something that in the past has generally been considered very complicated, and such a simplification should be welcomed by all.

Norman Litchfield: As consulting engineers for a number of railroads, we have been closely connected with the development of the modern catenary, and a short review may therefore be of interest.

The first major installation of high-voltage catenary was on the N. Y., N. H. & H. R. R., in 1906, between Woodlawn, N. Y. and Stamford, Conn., the main line construction using two messengers with diagonal hangers forming a *B* with the trolley.

On the electrification of the Elkhorn grade of the N. & W. R. R., in 1912 we employed a single catenary for both main line and yards, the necessary stability of the trolley wire being obtained by a cross-span wire installed only at points exposed to winds. The catenary was supported by suspension insulators hung below the body strand, thus eliminating insulation in the latter between tracks. The same construction was used by us on the Paoli electrification of the P. R. R. and has since become practically a standard.

The original New Haven construction used a square, latticed column, bolted to a concrete foundation. To provide a lighter appearing structure, and to reduce first cost and maintenance, the N. & W. R. R. and the P. R. R. adopted tubular poles set in cored holes in concrete foundations, the poles being guyed to concrete anchors at points of curve pull.

On a further extension of the N. & W. R. R., rolled-steel H-columns were used for the first time, with structural bases bolted to the foundations.

For the Virginian Railway electrification in 1923, we used H-columns with a pre-cast concrete base, cast on the pole at a central manufacturing yard. These were set in holes sheathed with a section of corrugated steel culvert pipe, then wedged in place, and backfilled.

During the past year we have been engaged in the electrification of the Bay Ridge freight line owned by the New York Connecting and the Long Island Railroads, and have used plain H-columns set in culvert pipe, then wedged in place and the pipe filled with concrete.

To obtain a very light appearance and a clear view of signals,

1. A. I. E. E. Journal, October 1927, p. 1081.
2. A. I. E. E. Journal, November 1927, p. 1200.
3. A. I. E. E. Journal, July, 1927, p. 675.
4. A. I. E. E. Journal, November 1927, p. 1220.
5. A. I. E. E. Journal, December 1927, p. 1307.

on the Paoli electrification, a cross catenary was used for the support of the messenger and trolley, this being its first general application to main-line work, although it had been used previously in the East Port Chester yard of the N. Y., N. H. & H. R. R.

Prior to the Virginian electrification, we had utilized galvanized steel wire and galvanized castings for the support of the messenger and trolley wire. On the Virginian, non-corrosive materials were used for the messenger and the trolley hangers (the two live elements above the trolley). For the Bay Ridge electrification, a further advance was made by the employment of non-corrosive hangers and wires throughout, including the cross-catenary.

Electrification is now under way of the P. R. R. Company's suburban service between Philadelphia and Wilmington which uses all non-corrosive materials. It is on a portion of this line that the interesting type of steady which is described in Mr. Viele's paper will be used.

At the time we undertook the Elkhorn grade electrification, we found the mathematics of the catenary system in an undeveloped state, the practise being to calculate the hangers only for those spans which followed around a uniform track curve, it being left to the construction forces to cut and fit the irregular spans at transitions, etc. On this line it became imperative to find some method of calculating the irregular spans also, and an original theorem was therefore developed by our engineers. This has since become generally used, and is described in Mr. Brown's paper. It should be remembered that while discussion of the mathematics is of value, nevertheless catenary design is largely empirical, requiring judgment and experience to produce an economical and smooth-running line.

H. S. Richmond: In abolishing the trolley pull-offs on high-grade and high-speed systems, by experience it was found necessary to meet the condition which demands that the trolley curve of one span shall be tangent to that of the adjacent span opposite the point of support. The trolley curve is not a true circle, but if the above condition is met, it forms a continuous and graceful curve, lying in a horizontal plane at the temperature for which the computations were made. We have deduced formulas by which spans are thus matched together or "balanced" both on regular curvature and on transitions.

The formula by which spans are "balanced" on a regular curve is

$$U = \frac{100008725\left(1 - \dfrac{T}{M}\right)\phi}{d\,\phi / d\,x}\,D\,S$$

and the maximum deviation Δ of the form of the trolley curve from the true circle is given by the formula:

$$\Delta = S\,D\left[\frac{S}{45900} - \frac{\phi - 1}{11470\,d\,\phi/d\,x}\right]$$

Here

S = the span in feet.

T = the combined trolley and auxiliary tension.

M = the messenger tension.

D = the track curvature in degrees.

U = the horizontal offset between messenger and trolley.

ϕ = the ordinate of the fundamental trolley curve referred to the system axis.

and

$d\,\phi/d\,x$ is the derivative of ϕ with respect to axial dimension, the particular values of the curve and its derivative at the point of support being used.

The deviation Δ, we have found to be a very small quantity and not of significance as regards conformity of trolley to pantograph center. In this we take exception to Mr. Brown's citation of this point as being an important limitation in the use of the inclined system. On the contrary, we find that the real limitations of this system for moderate curvatures lies in the length of the horizontal offset between contact wire and messenger at points of support and the temperature variation in vertical and lateral position of the contact wire.

J. C. Damon: Mr. Jorstad noted that in systems investigated, the tension used for the primary messenger of the catenary construction was considerably higher than his formula would give.

In the recent past, the tendency for catenary construction seems to have been to use very high-strength material for the messenger and to keep the sag as low as possible. Under these conditions, the stretch of the cable furnishes a large proportion of the excess length of the catenary curve over the straight-line distance between supports, and with a given uplift from the pantograph, the tendency for the catenary system to rise is consequently very great.

When the tension in the messenger per-pound-weight of the catenary system is reduced, the sag must be increased; but, in turn, there is less tendency for the catenary system to rise because of the pantograph uplift.

With the lower tension in the messenger cable, there is a greater variation of the height of contact wire due to temperature variation, but less variation due to the uplift of the pantograph.

Recently, there has been a tendency to put feeder capacity into the messenger, which generally increases the weight of the messenger and, in consequence, due to the pantograph, reduces the upward movement of the contact wire. By using a moderate tension and putting the necessary feeder capacity into the messenger, some systems get no appreciable wave traveling ahead of the pantograph. The Chicago, North Shore & Milwaukee Railroad, which uses the heavy type of construction with feeder capacity in the messenger, is, of course, a low-voltage railroad and quite different from the Pennsylvania main line; but it has an entirely non-rust construction of very heavy messenger, which has given satisfaction at fairly high speeds. The Illinois Central Railroad is another system in which the feeder capacity has been put in the messenger and has operated in a very satisfactory manner.

Mr. Viele contradicted the statement in my verbal discussion and stated that the heavier messengers with lower-tension per pound did not reduce the wave which went ahead of the pantograph. We are not, however, as far apart as our necessarily brief statements in the very limited discussion permitted would make it appear.

If there were absolutely unrestricted longitudinal motion of the messenger, Mr. Viele's statement would be correct and my statement would be wrong. On the other hand, if no longitudinal motion of the messenger from one span to another were possible, Mr. Viele's statement would be wholly wrong and mine, correct.

In actual practise, Mr. Viele has developed an extremely flexible catenary support system which approaches somewhat, although not entirely, the conditions of his assumption. On the other hand, most of the existing catenary systems, and, I venture to predict, a great many of the future catenary systems, will have bridges with saddle insulators, or short strings of suspension insulators, and conditions will be more nearly those of a completely restricted than of an entirely unrestricted longitudinal motion—in which case, my statements, which were relative only, will be correct.

A. G. Oehler: My question is essentially an elaboration of what has already been introduced by Mr. Manz. I should like to know how much the loop hanger does offset the increased rigidity at the points of support? How much is this variation in rigidity corrected by the use of a heavy contact wire, and is it or is it not desirable to use a flexible hanger to minimize this difficulty? Finally, is it necessary to worry about it?

K. T. Healy: It seems unfortunate that no place has been given in these papers to study the overhead distribution system costs. The future extension of electrification depends largely upon the abilities of the engineers and manufacturers to reduce the initial costs of the improvement, other things remaining equal. And a considerable part of this reduction must come in the distribution system, as this makes up from 25 to 35 per cent of the total cost of the electrification. Therefore, it is essential that the design of the overhead distribution system should, as a means of lowering costs, look not only to satisfactory operation but also to economical utilization of material and labor of construction.

As a general rule, economies of design are effected by a close study of the conditions and requirements at hand and an ample allowance for them, at the same time confining the design to these only. The main conditions affecting overhead design are: first, amount of conductivity to be provided; second, speed and method of collection of the current; and third, climatic conditions.

The requirements of conductivity immediately make a line of demarcation between high- and low-voltage systems, systems in level country and in mountainous country, and multiple-track and single-track systems. With the high-voltage systems, under all but mountainous conditions, ample conductivity can be secured in two conductors, so that there is no reason, so far as conductivity is concerned, for going into design with more conductors. With the low-voltage systems, more conductors are necessary with the consequent heavier loadings on supporting structures and greater amounts of steel necessary in the structures.

The second condition affecting overhead design—namely, speed of collection,—imposes on main-line, high-speed tracks, requirements decidedly different from those on yard and siding tracks. To a large degree collection is a function of the ability of the collector to keep in physical contact with the overhead in spite of variation in height of the overhead or varying hardness of the overhead. The ability to follow variations in height is dependent upon the velocity and lineal rate of variation in the height of the overhead with a given effective inertia of the collector. In yard operation the speeds are low and the currents low, so that greater lineal rates of variation in height are allowable and consistent with good collection and the overhead distribution does not necessarily have to be of the full catenary type. In Europe, notable strides have been made in decreasing the cost of yard electrification by taking advantage of this fact. The Swiss have their Renens yard arranged with a modified direct suspension, with 116-ft. and 165-ft. spans. This has given very satisfactory operating results.

The Paris and Orleans Railroad, on its 1500-volt electrification, has followed the same trend and has wired its yards in the Paris area with a direct suspended system with cross-span supports. Thus, many economies are possible by designing yard distribution systems, not for mainline track requirements, but for yard requirements of low-speed and less exacting requirements of uniformity in contact wire.

The second condition also has to do with the method of collection. Here again it may be well to emphasize Mr. Viele's remarks to the effect that coordinated effort in the design of both pantograph and overhead is necessary for satisfactory operation and that this coordination may be carried even further to effect economies in cost. Certainly one of the most important factors in the ability of a collector to work well is the inertia of its moving parts. Here, European pantograph design has taken a different course from ours on high-voltage systems by introducing a secondary bow for the shoe, swinging about its own central axis and held in position by small springs. This has reduced the effective inertia of the collector many times, because this small bow, weighing only a few pounds, is all that has to move to follow the small irregularities of the trolley height. It then requires much lower pressures to keep continuous contact on the trolley wire with consequent reduced wear on both wire and shoe. At the same time, the pantograph itself is made much lighter, using wire guys instead of pipe for side bracing and snugger joints with less friction at the points of support and other axes. This requires less pressure to operate and makes a smaller area for wind and ice loads to affect. The effects of hard spots in the contact system are of course greatly diminished because of the much lighter weight behind the impact of the shoe on the hard spot. Experience shows that a single shoe will collect 180 amperes perfectly at 55 mi. per hr. and 250 amperes at 27 mi. per hour, and that the shoes will run from 5600 mi. in Switzerland to 15,000 mi. in Germany. The usual practise is to run with two pantographs up, which nearly doubles the life of the shoes. The greasing of the shoes seems to be a mooted question; the Swiss, for instance, are in favor of it and the Germans are not.

Mention has been made of the need of coordinated effort in pantograph and catenary design, but the importance of this in relation to reducing both initial and operating costs cannot be stressed enough. With the low currents of normal high-voltage overhead distribution and the resulting possibilities of reducing shoe pressure, the possible simplification in catenary design is considerable.

In all the high-voltage European electrifications, this coordination has resulted in a great saving. Pantograph pressures have been kept down to 79 lb., using aluminum shoes with negligible wear on contact wires. As a consequence they have been able to use a much lighter and simpler catenary system with only a messenger and contact wire. In the past, to cut out the hard spots of the hangers, they have operated with an auxiliary or intermediate wire, but with the flexible hangers they use, they have found this wire unnecessary. In some cases the flexible hangers are made of strand so as to make a low-resistance, non-heating connection between messenger and contact. Particular care has been taken to avoid hard spots; splicing is rare, the contact wire being in lengths sufficient to reach from anchor point to anchor point; push-offs and other devices with compression members are not used; rigid deflectors are not used; and pull-offs are made very light.

The Swedish State Railroad catenary may be taken as an example of this type of catenary designed for weather conditions comparable to ours and with a conductivity of about 260,000 cir. mils. The costs of the materials at our prices would be about $528 per mile for 80 sq. mm. copper contact, and $316 per mile for 50 sq. mm. copper messenger, a total of $844.

A corresponding example of American practise may be a 4/0 phono contact, costing $792, a 4/0 copper wire, costing $686, auxiliary clips, costing $35, and a 9/16-in. steel messenger, costing $316, or a total of $1829 per mile, nearly $1000 more per mile than the other for a slightly greater conductivity of 310,000 cir. mils. The unit weights of the two systems are 0.81 lb. per ft., for the first and 1.95 lb. with the American, requiring a pole designed for roughly twice the catenary loading. This, of course, means an opportunity for the saving of considerable weight in the steel structures. The Swedish construction, using two 5-in. channels for a self-supporting single-track line, is comparable to the 10-in. H-section poles in use in this country for similar construction.

H. F. Brown: Mr. Thorp's paper among other things brings out the importance of the catenary profile in determining the structure heights and catenary details, especially where the hanger rods depart from standard conditions. This is a very valuable check on the calculations.

The unit weights and required conductivity of the overhead system described are impressive, but, of course, are required for the low voltage used. This is further reflected in the size of the supporting structures. I believe 14-in. H-beams were used for the typical two-track bracket poles illustrated in Fig. 15 of the paper. For the lighter type of catenary permitted by the higher voltage used on the New Haven, a 12-in. section is ample for similar two-track spans.

While Wade and Linebaugh show the feasibility of designing an overhead contact system which can transmit and deliver very large currents, and also the possibility of collecting large amounts by sliding collectors moving at high speeds, one cannot escape questioning the economics of a system which requires more than seven pounds of copper per foot of track, in the contact system alone.

If electrification is to be economically applied to steam railroads on any large scale, it must be done on a basis which gives the minimum new capital requirements. One of the largest items is the cost of the distribution system. The trend should, therefore, be towards lighter designs rather than heavier, indicative of higher voltages.

It is noted that the test track described contains no turnouts, heavy curves, or low highway bridges. With the high pantograph pressures required, the real test of current collection will come at points of special construction, such as deflectors, pull-offs on heavy curves, and the hard spots under low bridges; and while such difficulties might be overcome, they nevertheless increase at least in proportion to the catenary weight, and the amount of current to be collected. The wear on both the collector shoe and the contact wire must be greatly increased under such conditions, even with lubrication.

Mention was made of the use of a 6/0 conductor as being undesirable. Our experience seems to indicate that there is a real field of use for such a wire on busy yard leads and ladder tracks, where traffic is dense, and pantograph passages very frequent, and we have installed 6/0 wire in such locations to secure longer wear.

One word about lubrication. This is something to be desired but difficult to secure in actual practise, especially on a large system. If the lubricant is applied to the pantograph shoe at the start of a run, it is soon worn off in the first few miles, and the terminal-track trolleys are the chief beneficiaries. Tests made on the New Haven seem to indicate that the best shoe mileage and least wire wear is secured with a mild-steel shoe, and a pantograph pressure of about 18 lb.

Pantograph design is capable of being greatly refined. Lighter weights, lighter pressures, and lower inertias, especially of the collector shoe itself, seem to be the chief desiderate, all of which are inconsistent with heavy current collection.

Mr. Jorstad, in his paper, limits the shape of the trolley alinement to that of a true parabola, and shows that his formula, which gives the ratio of the weights of the two opposing systems (messenger and contact) equal to the ratio of their respective tensions, applies to the parabolic shape.

The use of this formula would therefore limit the designer in the choice of sag, or would fix the weights and sizes of the main members (messenger and contact) regardless of their economic choice.

As an illustration, assume that a 4/0 copper wire is the required contact member, with a normal tension of 2000 lb. The unit weight is 0.641 lb. and from the formula,

$$0.641\ T_m = 2000\ W_m \text{ and } T_m = 3120\ W_m$$

If we assume a 7/16-in. steel messenger, which past experience has shown to be of ample strength, properly sagged, for a 4/0 wire, its unit weight is 0.415 lb. and the tension, by the above formula will be 1300 lb.

The resulting catenary will weight approximately, including hangers, 1.15 lb. per ft., which would give a sag in a 300-ft. span of nearly 10 ft. This is obviously too great.

To decrease this sag to an economic value, the tension must be increased, which, according to the formula, must be accompanied by an increase in weight. To produce a 5-ft. sag, it would be necessary to go to a messenger having a unit weight of nearly three times the above, since the total weight is rapidly increasing. Assuming a unit messenger weight of 1.6 lb., the equivalent messenger tension would then be 5000 lb., and the resulting total weight of the catenary would be 2.3 lb. with a sag of 5.17 ft. This messenger would be approximately 7/8 in. in diameter, which is obviously not economically applied, as the material is not required for the low tension used.

It is true that the trolley tension may be increased. The ultimate strength of the wire assumed is approximately 8000 lb. but it should not be stressed much more than $^2/_3$ of this amount on account of the low yield point of copper, and the danger of permanent stretch. This limits the maximum working tension to about 5300 lb., and sets the normal working tension at about 3000 lb.

Then, from the formula,

$$0.641\ T_m = 3000\ W_m \text{ or } T_m = 4700\ W_m$$

For a 5-ft. sag, the messenger must weigh approximately 0.671 lb. per ft. and the tension would then be 3140 lb.

This indicates a 9/16-in. messenger, which, although more nearly the economic size, is nevertheless larger than required, and is not working to its full capacity. Further, the horizontal loads on the structures on curves, due to the trolley tension, have now been increased 50 per cent, requiring this additional strength in such structures.

If, however, the characteristics of the design will permit the application of Mr. Jorstad's formula, it presents a very valuable method, and greatly simplifies the calculation, since the shape is parabolic. It may be mentioned here that the earlier installations on the New Haven, where the spans were short, were designed on the theory that the shape was parabolic.

Sidney Withington (by letter): The design of pantographs in this country just at present, is, I believe, the least developed part of any of the electric equipment. We depend upon a collecting device capable of variation in height up to 10 ft., as mentioned by Mr. Viele. The inertia of such apparatus is very great and at high speeds, as pointed out by Mr. Viele, this is a serious problem and requires a very considerable pressure against the wire to avoid arcing. This, in turn, limits the design of the catenary system. The standard pantograph used abroad, which employes a trailing bow above the main pantograph, would seem to be considerably more logical. The trailing bow, being relatively light, follows the wire satisfactorily even at relatively low pressures, and the result is a far lighter catenary design with consequent economies both of construction and maintenance and without serious limitation in the amount of current which can successfully be collected. The advantages which would accrue from an improved design of pantograph in this country would repay, I believe, a very considerable amount of study.

Mr. Viele mentions spans of 325 ft. for the catenary system. It has been the experience on the New Haven that unless the location is pretty well protected from wind, some form of lateral support for long spans is necessary between bents in order to prevent trouble due to wind under maximum conditions. These supports may be obtained in the form of bridles or additional independent steady spans, or by shortening the main span.

The form of support suggested by Mr. Viele is of interest. A somewhat similar arrangement was installed on the New Haven in 1919. Other things being equal, it is of advantage to separate mechanically, as far as possible, each track from the others, in order that trouble which may occur may be localized. One advantage of the scheme mentioned by Mr. Viele is that the insulators are not directly over the track, and where steam locomotives are operated along with electric operation this is of considerable advantage.

Mr. Viele mentions hard spots aud their damping affect on the oscillation which proceeds ahead of the pantograph. On the New Haven electrification, where wood section breaks were used at points of high speed an approach was designed consisting of a sheet-steel member of light gage about 6 ft. long, with the idea of damping the oscillations before they reached the relatively heavy section break. It was, however, found that this was not necessary, and its use has been discontinued. It is of course true that so far as possible, wood-stick section breaks are not used at points of high speed. Indeed, even splicing sleeves are eliminated so far as possible.

It may be of interest to note that on the New Haven electrification extensions installed in 1912 and 1913, the steel catenary supporting structures were designed to be self-supporting as units; that is, the corner connections between the truss and the posts were arranged to take the stress normal to the track due to wind, curve pull, etc., the anchor bolts at the base of the posts taking shear only. This is indicated in the shape of the posts, which taper down from the truss or corner connections.

This saved a considerable amount of concrete as compared with the original design wherein the posts were self-supporting and the concrete bases were obliged to take the entire overturning moment. There was some additional weight of steel and additional field labor, but the design resulted in considerable net saving.

In some of the supporting structures, especially those for six tracks, it was found advantageous to assume a point of contraflexure about 7 ft. above the top of the foundation. This resulted in some saving of weight of steel without much increase in the size of the foundation.

The magnitude of current collected from a trolley at 500, 1500 or 3000 volts is of course far greater, other things being equal, than that collected at 11,000 or 22,000 volts, and the problems are therefore of somewhat different nature when the lower voltages are considered, both from the point of view of current-carrying capacity in the catenary system itself, and what might be called the "commutation" at the point of contact.

The problem of sparkless collection of current is a function of the smoothness of the contact system, which in turn depends upon its uniformity of suspension—that is, the contact wire should be either free to move in a vertical plane easily at all points upon the passage of the pantograph collecting shoe, or should be relatively rigid at all points. Any change from soft to hard construction means sparking or arcing at high speeds. The real test of sparkless collection occurs at turnouts and at low bridges and other points where construction is limited by local conditions.

Mention is made of the freedom from burned messengers on the Chicago, Milwaukee & St. Paul at loop hangers, which are employed on that system. The real test of efficiency of loop hangers would occur, I believe, only where the individual substation capacity feeding the system is relatively larger than is the case on the Milwaukee.

The design of pantograph shoe support with 4 in. of play between upper and lower position on the top of the pantograph is of much interest. It would seem that somewhat delicate adjustment would be necessary in order to maintain the supporting apparatus at the mid-position of its travel under normal conditions that it might be free to move up or down as roughness in the contact system required. Details of design to accomplish this would be of interest. Some data also would be of interest as to the mileage made by the "pans." The pressure of 40 lb. seems high when compared with that where less current-carrying capacity is required. A pressure of 40 lb. also means a necessarily heavy contact system, regardless of current-capacity requirements.

The economic limitations of any contact system, I believe, occur in the weight and expense of installation of the conductors and supporting structures rather than in the amount of current which can be successfully collected under conditions of high speed, and this should be considered in the design of an electrification installation. It is possible that the use of higher voltages, either alternating or direct current, would be justified in some instances by the saving of material in the contact structure.

S. M. Viele: Mr. Brown asked the effect of tension in the contact wire on vertical movement. We have not made any experiments on the basis of varying contact-wire tension. My opinion is it would not make any material difference.

Mr. Manz asked about the effects of unloading the span. Mr. Damon's remarks were along the same line. I do not interpret upward deflections in the span on the basis of the possible impression that some have of that statement. If we assume a condition in which the span involved has a unit weight of 3 lb. per ft. and say a 300-ft. span, it means that the messenger is carrying roughly 900 lb. If we operate five pantographs on the span, it means that instead of carrying 900 lb., it carries 800 lb. This means that the sag in the span has to be reduced on account of the tension remaining practically constant. Therefore, the messenger sag will be decreased; the extra length of messenger will run back in the successive spans.

Now, if you change the contact tension, or if you change the loading of the span without change of pantograph pressures, it will not make a great deal of difference in the upward deflections with passage of the pantographs.

Mr. Oehler asked the question "What does it amount to?" Deterioration of contact wire has a very material bearing on how much it costs to operate such construction. Spliced contact wire means a deterioration of roughly five times that without splices. Whether we get a life of ten years out of it or 50 years is very material.

The question may also be asked "What are the relative effects of variation in height of contact wire?" Such effects are relatively small as compared with spliced effects. However, all variations of whatever nature which take place in the contact-wire height involve variations of pressure, both in enlarged and decreased pressures. Increased pressures mean increased wear; decreased pressures mean burning of the contact wire. Both result in increased maintenance cost. It is simply a question of the relative reduction of section which is produced by such variations in height, with the resulting cost. They have not been evaluated in money, though they have been evaluated in my mind as being worthy of study and the correction of value.

H. F. Brown: In answer to Mr. Litchfield I will simply state that the method of eliminating the cusp shown in Fig. 41 is admittedly an overcorrection. The importance of this correction is greater if the trolley tensions are lower. On the New Haven system, the tensions of the trolley and the auxiliary are lower, I think, than on many of the other systems mentioned here today. For that reason, the cusp effect is more important in their inclined design than it is where the trolley tensions are higher, and the method used in the paper is shown instead of the one referred to by Mr. Richmond because it was desirable to make this correction apply to all conditions involving even high temperatures as well as the normal temperatures. It is true that if one goes into the mathematics of the paper, the method suggested by Mr. Richmond is absolutely correct for normal conditions.

R. E. Wade and J. J. Linebaugh: Mr. Brown, in his written discussion with reference to tests on the collection of large currents from overhead wires as conducted at Erie, Pa. mentions the use of "more than 7 lb. of copper per ft. of track in the contact system alone."

The actual total weight of copper, installed per ft. of track for the tests involving the unusually large current values quoted, and for both feeder and contact, was 4.7 lb. maximum with 1,000,000 cir. mil feeder messenger and 3.92 lb. in the section with 750,000 cir. mil feeder messenger. With multitrack work and automatic cross ties, these weights would be reduced even for the lower voltages used.

While it is true that the recorded tests were conducted without deflectors, hard spots under bridges and pulloffs on heavy curves, temporary low bridges were later installed, and satisfactory collection demonstrated with a 1 per cent gradient in contact wires. Experience on lines in operation shows that with two contact wires, flexibly supported throughout, the additional wear at such points is negligible with pantograph pressures as high as 35 lb.

As regards lubrication, while it would of course be desirable to operate without this feature, experience has shown that even with comparatively infrequent service, satisfactory lubrication of contact wires can be maintained, although as stated by Mr. Brown, the contact wires within and in the vicinity of the large yards receive more lubrication, particularly in and near overhead switches. This also applies to curves due to wiping action.

While it is unquestionably true that generally speaking it is desirable to make refinements in pantograph designs as regards weights, lighter pressures, and lower inertias, it is commonly agreed that coordination in the design of both pantograph and overhead is necessary, and there is some question as to whether such coordination is not approached with the relatively higher pantograph pressures in combination with the weight of two wires in the same horizontal plane as compared with the very light pressures and correspondingly light overhead construction as used in some European installations.

Mr. Withington in his discussion very properly emphasizes the desirability of uniformity of suspension for contact wires, that is, the freedom of movement in a vertical plane at all points. By suggestion this of course includes uniformity in weight, which of course cannot be realized on account of the necessity for overhead switches and certain fittings attached to contact wires. From our observation, if the contact wires are free to move in a vertical plane at all points of suspension, the additional wear imposed on contact wire is reduced to a minimum.

As referred to in our paper, with regards to the freedom from burned messengers with loop hangers, we would suggest that in the case referred to, the current demand at locomotive rather than the substation capacity would be the determining factor.

As regards the flexibility of the pantograph shoe mounting, while this of course does not compare with the commonly used European design, either as to delicacy or range, there is no question but that the small amount of movement provided is a valuable asset, particularly with the flexible contact-wire suspension referred to elsewhere.

There is no question but that on some systems contact-wire splicing devices are responsible for considerable trouble in that the designs commonly used enclose the contact wire and offer an obstruction to the collector shoe, which becomes worse as wear on the splicing device increases. A splicing device which permits uninterrupted contact with the wire and is of the minimum weight consistent with the requirements, will do away with this trouble to a large extent. Such a device is available.

REPORT OF COMMITTEE ON PRODUCTION AND APPLICATION OF LIGHT[1]

(MILLAR)

DETROIT, MICH., JUNE 22, 1927

E. A. Williford: (communicated after adjournment) I should like to augment the information given in this report on the production and application of ultra violet light for medicinal and industrial purposes.

The chief natural source of ultra violet light is the sun. There are, however, many artificial sources of ultra violet light, among them being the various forms of carbon arcs, the mercury vapor arc in quartz, and other metal arcs.

The emanations from the mercury arc are confined to certain bands of wavelengths, especially in the shorter wavelengths in the region of 2200 to 3200 Angstrom units, with very little continuity of the spectrum. Every different metal gives its own characteristic quality of radiation when its vapors are introduced into the arc stream. It is possible, therefore, to control the quality of the radiation by modifying the chemical composition of the electrodes; or, in the case of the carbon electrodes, the composition of the core. The following are typical instances:

Arcs between pure carbon electrodes give ultra violet light chiefly of wavelengths from 3600 to 4000 Angstrom units.

If the electrodes are of nickel or if carbon electrodes are impregnated with nickel, a large proportion of the ultra violet is in a band from 3400 to 3600 Angstrom units.

Similarly, aluminum gives much radiation in the region of 2950 to 3300 Angstrom units, while cobalt gives an arc rich in the very short wavelengths from 2200 to 2500 Angstrom units and again from 3300 to 3500 Angstrom units.

Iron gives a large amount of radiation through the entire ultra violet spectrum. Cerium and the other rare earths give ultra violet from 2900 Angstrom units to the visible spectrum, quantitatively and qualitatively very similar to the spectrum of sunlight. For this reason, carbon electrodes impregnated with these rare earths have been found by the Bureau of Standards to be the nearest in quality to natural sunlight of any known artificial light source.

The materials referred to above are not toxic. They can, therefore, be used as arc electrodes without enclosing globes and without danger of toxic poisoning. If required for special applications, the arcs can be isolated from the surrounding atmosphere by suitably ventilated housings constructed partly of quartz or some of the newer ultra violet transmitting quartz substitutes.

These metals, if used as pure electrodes, give satisfactory arcs on two or three amperes of direct current. If the metals are used to impregnate carbon electrodes, so as to make the so-called impregnated or flaming arcs, they can be operated satisfactorily on either alternating or direct current at amperages from 2 to 150. Because of this wide range of energy consumption possible, any desired quantity of the particular type of radiation required can be obtained with these arcs.

The known applications of these different types of radiation are as varied as the qualities of the arcs themselves. For instance, those arcs giving long-wave ultra violet light are especially valuable in the photographic, photo-engraving, and blueprinting industries.

The arcs which give light similar to sunlight are essential in dye-fading and paint-testing work where such materials are ordinarily to be used in sunlight itself. Artificial sunlight from these arcs also is utilized by physicians to augment natural sunlight or to substitute for it when natural sunlight is not available in the treatment of tuberculosis and rickets.

Other electrodes containing metal are used when it is not necessary to attempt to duplicate sunlight. Such cases are those where it is sought only to produce a tan or artificial sunburn. Those arcs giving very short-wave ultra violet radiation give large amounts of light having a powerful sterilizing or germicidal action.

From the foregoing, it is apparent that it is possible to make a selection of an artificial source of ultra violet light that will best accomplish almost any work which requires the use of ultra violet radiation.

POWER GENERATION[1]

(W. S. GORSUCH)

DETROIT, MICH., JUNE 22, 1927

Philip Torchio: Electrical engineers should have particular interest in following the development of the size of the generators. The report states that there is a 208,000-kw. unit under construction. It should have said that it consists of three machines cross-compound. If I remember rightly, the largest single unit in operation in the New York Edison 60,000-kw. The Edison-United Companies have a large cross-compound 160,000-kw. unit on order and placed an order June 21 for a 165,000-kw. unit. The generators of the unit order last year are, one, 85,000-kw. and the other 75,000-kw. and, for the unit ordered yesterday, the generators will be 80,000-kw. each.

In pointing this out, I am not saying that the manufacturers are not ready to make larger generators, because, as a matter of fact, for another installation for which we are now securing bids,

1. A. I. E. E. JOURNAL, October, 1927, p. 1022.

1. A. I. E. E. JOURNAL, September, 1927, p. 916.

we already have offers of more than 100,000 kw. in one unit, and probably single units larger than 125,000-kw. will be obtained.

Another point that I wanted to bring out in this general review is that while we are making great progress in saving coal, it is nevertheless our duty not to let the public misunderstand how we accomplish it. The truth is that we are saving coal by spending more in investment in plants. It does not necessarily follow, once we consider the total cost, that we are making such radical improvements which might lead the public to assume that the cost of power is also rapidly being reduced. The cost of power is being reduced, but at a gradual, moderate rate. We are making great advances in saving coal, but we are putting more capital in our plant investment to secure those higher economies. An extreme illustration of this is the Dutch Point station with the mercury boilers and similar installations throughout the country.

F. A. Scheffler: My discussion of this report is more particularly an addition to the table of the pulverized-coal installations in the country.

The installations in operation last year consisted of an installed capacity of 2,200,000 kw. and those under construction, 440,000, making a total of 2,640,000-kw. capacity installed.

Assuming that these stations, of which there are about thirty-eight, average an annual load factor of 50 per cent, the output would be 9,414,810,000 kw-hr., and also assuming that the average coal consumption is 1½ lb. of coal per kw-hr., the total fuel used would be 7,061,100 short tons per year.

During the year 1927, the total coal consumption in public utility plants in the United States was 41,245,000 short tons.

The ratio of the total coal used in pulverized form to the total coal consumption, is therefore approximately 17 per cent.

In addition to the above, there are under construction new plants and additions to others as follows:

Station	Company	Kw. capacity installed
State Line	State Line Generating Co.	208,000
Toronto	Ohio River Edison Co. (2-30,000 kw.)	60,000
Glenhead	Long Island Lighting Co.	25,000
Trenton Channel	Detroit Edison Co.	50,000
Aurora, Ill	Western United Gas & Elec. Co.	10,000
Pekin, Ill	Super-Power	50,000
Montaup	Montaup Electric Co.	40,000
		443,000

With the exception of four or five on the above list of generating plants, all of the stations were new ones built during the last seven years.

There are five or six other utility plants using pulverized coal, which are not listed above, because they are not primarily power plants for generating current, but are used more for steam heating purposes. Some of these are as follows:

Puget Sound Traction, Light & Power Co., Seattle, Wash.—capacity about 8500 boiler h. p.

Allegheny Heating Co., Pittsburgh, Pa.,—capacity 10,000 boiler h. p.

Lockport Light, Heat & Power Co., Lockport, N. Y.—capacity 2500 boiler h. p.

New York Steam Co., 36th St. & East River, New York—capacity 30,000 boiler h. p.

Rochester Gas & Electric Corp., Lawn St. Station, Rochester, N. Y.—capacity 250,000 lb. steam per hr.

W. S. Gorsuch: It is important, as Mr. Torchio has pointed out, to state the type when referring to a certain size generator unit. This has been done in every case in the report, not in the brief outline of progress in the art of power generation, but in the description that follows, in which outline drawings are also given for exceptional designs. It will be noted that the plan of this report is first to give a general statement of the trend of the art in each class of power-station equipment and then under the heading "Outstanding Installations" a full description is given of the equipment referred to in the preceding general statement.

Reference has been made to the remarkable economies brought about in fuel burning stations and the additional investment cost to achieve these results. In this connection I believe because of the increasing number of interconnections a comprehensive study should be undertaken at this time to show the relative cost of power of hydroelectric and steam plants, and also the relative merits of the two systems.

POWER TRANSMISSION AND DISTRIBUTION[1]

(PHILIP TORCHIO)

DETROIT, MICH., JUNE 22, 1927

D. W. Roper: This report calls attention to some of the lightning arresters and distribution circuits in Chicago. For fear that the readers might get a wrong impression, I want to add a little to what appears in the report. The lightning-arrester records of the several types appeared to indicate that the results obtained were not quite what were expected. Further investigation of that point has brought out an interesting feature, somewhat unlooked for, in that some of these burn-outs which have been recorded and which have affected our results were due to lightning entering via the secondary circuits. The lightning arresters we have are on the primary circuits. The primary distribution, in general, occupies the top arm and the secondary ordinarily the next lower arm. Sometimes it is on the same arm with the primary circuits. As the lightning potentials which appear on the line are in proportion to the height from the ground, it is seen that the secondary circuits have been getting almost the same lightning effects as the primary.

We have examined a few transformers—not very many—but as nearly as we can determine from the few which we have examined, something like one-third of our transformer burn-outs have been due to lightning which entered the secondary winding. We can hardly blame the lightning arresters which are connected to the primary circuits if some transformers burn out due to lightning entering on the secondary circuits.

S. J. Rosch: The report under the paragraph on Underground Cables, says, "There is a pronounced drift toward the use of single-conductor cables and three-conductor metal-sheathed unbelted cables." I believe it would be highly advisable in view of its importance, to include in this report some figures indicating the quantity of the latter type of cable now in use in this country. Undoubtedly, many operating engineers in making up their 1928 budget, will naturally look to this and similar reports, for an indication of what type of cable to purchase for their three-phase circuits, whether to use three-single conductors, the regular belted three-conductor cable, or the metal-sheathed unbelted type. It would also be of value to have some figures on the probable use in the near future, of the latter type of cable.

Alfred Herz: I have one question in mind in regard to the inter-bonding or grounding of cable sheaths. We all realize that considerable longitudinal voltage makes its appearance in those sheaths, especially in a sheath surrounding a single-conductor cable. What is the practise in taking care of, or rather in avoiding detrimental effect when you bond or ground such cable sheaths?

Philip Torchio: Answering Mr. Rosch's inquiry as to what per cent of three-conductor cable is now of the metal-sheathed unbelted type, I think there is a very small amount in use at the present time but several manufacturers are ready to make it and a considerable demand for it is anticipated.

Regarding the surge voltages on underground cables as indicated in the report the maximum recorded was 4.6 times normal. Now a cable which is operated at 40 to 50 volts per mil is tested at about 165 volts per mil so that the normal 5-

1. A. I. E. E. JOURNAL, July, 1927, p 691.

min. test voltage is about four times the normal operating voltage. There remains still a large margin above the test voltage before actual breakdown is reached so that a surge of 4.6 times normal especially in view of its brief duration should not give deterioration. This is in further explanation of the Committee's intent in giving that view.

Replying to Mr. Herz's question about taking care of the induced voltages and currents in the sheaths of single-conductor cables, that can be done by providing insulating joints in the sheaths and cross connecting the insulated sheath sections in such a manner that the induced voltages are counterbalanced. As an alternative the insulated sheath sections may be grounded at one end giving a voltage normally of a few volts at the other end of the section which may under short-circuit conditions reach values of the order of 100 volts.

Herman Halperin: (communicated after adjournment) In the last part of the report, there is a discussion regarding the migration of oil from oil-filled joints into cable, and it is stated that the oil "no doubt reduces or possibly eliminates voids, especially near the joints." Then, at the end of the same paragraph is the following: "The use of such oil-filled joints makes it possible that satisfactory single-conductor cables of the usual type of construction may be obtained for operation at 110-kv., 3-phase."

Up to a few years ago, joints were the limiting feature for underground cables in going to higher voltages, but with the recent development in joints, this limit has been removed. In connection with the last quotation, if the cable as it leaves the factory is not of a quality to give satisfactory operation at 110-kv., 3-phase, then, according to experience with cable made in the past year, the addition of oil-filled joints will not make the cable operate satisfactorily. Apparently, this was not the intent of the quoted statement, but one might infer it from reading the report. Operating and laboratory data indicate that the principal factors necessary to obtain satisfactory 110-kv. cable are either to improve the quality of cable insulation furnished in cables of ordinary construction, or change the cable construction, or both.

In Chicago, No. 10 transformer oil has been used for filling about 150 three-conductor, 33-kv. joints and 750 single-conductor, 75-kv. joints. There have been occasions to examine the joints and cable adjacent in connection with cable failures, and the insulation next to the joint has been usually found well impregnated, partly due to the migration of oil from the joint into the cable insulation. However, considerable deterioration has been found in the cable insulation as close as 2 ft. from the joint.

In connection with laboratory tests on 75-ft. lengths of single-conductor, 75-kv. cable and also with lengths that had been in service several months, dissection has shown that the distance the oil traveled from potheads or joints, varied from a few feet next to the sheath to a maximum of about 50 ft. along the strands of the conductor, depending on the kind of impregnating compound in the cable insulation. The penetration of the oil readily into the insulation was for only a few layers, except for the few feet of cable mmediately adjacent to the potheads or joints.

Operating experiences with underground lines and tests on cable samples have indicated great variations in the quality of insulation along the length of cable.

Apparently the effectiveness of oil in improving the quality of the insulation is practically limited to only a few feet, which is very short in comparison to the length of a section of cable between manholes that may be 400 to 700 ft. long.

W. A. Del Mar: (communicated after adjournment) The maintenance of impregnation is now recognized as an essential element of success in the operation of high-tension cables, and the report clearly calls attention to the distinction between the use of oil-filled joints with reservoirs and the hollow-core type used on the 132-kv. circuits at Chicago and New York.

Another distinction which might be made is between two variants of the former type, namely, cables in which the reservoirs are used merely to maintain the impregnation and those in which they are used to maintain a definite pressure within the cable. The former type is subject to limitations, especially where the cable is impregnated with a jelly compound, as the reservoir oil penetrates very slowly, and there is a tendency for the residual air to accumulate near the center of the section of cable. The latter type, *i. e.*, where the system is designed for pressure maintenance rather than penetration, assumes that air will be present and provides means for making it harmless. This is done subjecting the air to such pressure that it will not ionize at the existing dielectric stress.

An experimental installation of this kind has been made in Detroit, bellows reservoirs being used, which are kept under a pressure of approximately 0.4 atmosphere above normal by means of weighted lever. The desired pressure was predetermined as indicated in the discussion of my paper on *The Effect of Internal Vacua*, JOURNAL A. I. E. E., Oct. 1923, p. 1012, *i. e.*, the maximum dielectric stress in the cable was calculated and the air pressure determined at which thin air films begin to ionize at this stress. The reservoir pressure was set slightly above this point.

It is obvious that the success of this pressure system depends to some extent on the use of cable impregnating compound which is fairly soft or fluid at operating temperatures.

APPLICATIONS TO MINING WORK[1]

(LESSER)

DETROIT, MICHIGAN, JUNE 22, 1927

A. M. MacCutcheon: I should like to ask the committee if they can give us any more detail on the progress in getting apparatus approved with an unqualified approval of the Bureau of Mines. As I understand it, they give limited approval to certain types of apparatus. I have not yet learned that they give unqualified approval of types for use in gaseous mines. In talking to the people of the Bureau of Mines at Pittsburgh about two years ago, my conception was that they are approving apparatus because it is the best there is, but it is not thoroughly satisfactory. They said that if they used tests that they would be satisfied with, there was nothing on the market that would stand them. They said, "We are not giving unqualified approval. When we get the right kind of apparatus, we will give unqualified approval." I was wondering if apparatus now gets unqualified approval.

E. J. Gealy: Under the subject of permissible equipment, the industry is today getting much equipment which it has needed for a long time. Every piece of permissible equipment is given what the Bureau calls a "permissible approval plate." That is, it is approved only as long as it is kept in the condition in which the Bureau had it when it was inspected, so, it is what you might call "limited."

Aside from that, there is being developed other equipment which is not strictly permissible, but is of a better type for mining service. That will probably result in what we might call "a semi-permissible type of apparatus."

W. H. Lesser: The only question to be answered was Mr. MacCutcheon's question, and Mr. Gealy answered that. I don't know now whether the Bureau of Mines will issue a plate showing unqualified approval.

1. A. I. E. E. JOURNAL, October, 1927, p. 1032.

AN INVESTIGATION OF CORONA LOSS[1]
(STARR AND LLOYD)
LAW OF CORONA AND DIELECTRIC STRENGTH
(PEEK)

DETROIT, MICH., JUNE 24, 1927.

V. Karapetoff: The diagram of connections used by the authors permits of obtaining an oscillogram of the total current, consisting of a reactive charging component and an in-phase energy component. In some cases it may be of interest to obtain a picture of the latter component alone. Perhaps this could be accomplished by some differential arrangement; that is, by using a condenser which takes the same reactive charging current as the conductor under test but has practically no corona loss. The high-voltage side of the step-up transformer would then be wound for a double voltage, with the middle point grounded; the added condenser would be connected to the other terminal of the transformer, and the resistance R_3 would be connected to the neutral point. Only the difference of the currents taken by the conductor under test and the perfect condenser would flow through R_3.

A Mechanical Transcriber. With an increasing use of the cathode ray oscillograph in practical work, the problem of rapidly transcribing records with a sine-law axis of abscissas to those with Cartesian coordinates becomes one of considerable importance. Where hundreds of similar records have to be transcribed, the tedious point-by-point method of transfer of individual ordinates can hardly be considered satisfactory. A mechanical transcriber is a device consisting of kinematic connections with a stylus at one end and a pencil at the other. By going with the stylus over the outline of an oscillogram on a photographic film, the pencil is made to draw on a strip of paper the corresponding curve in rectangular coordinates.

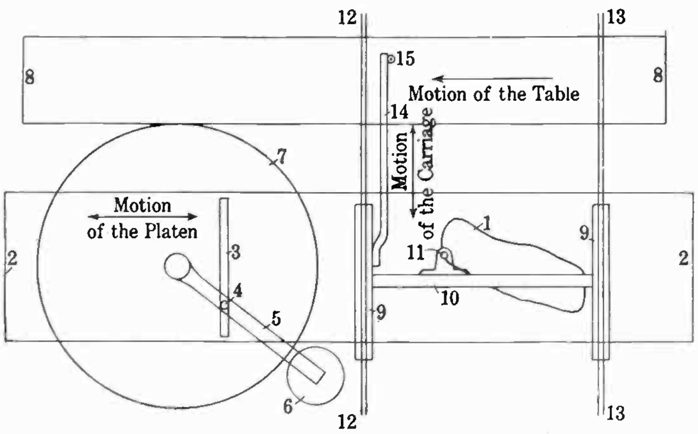

FIG. 1

In order to enable those interested to build a mechanical transcriber, the underlying principle is shown in Fig. 1 herewith. The film containing the record is fastened to the platen 2-2, which has a slot, 3. A pin, 4, attached to the crank, 5, can slide in the slot. When the crank is turned by means of the handle, 6, the platen and the oscillogram perform a harmonic motion along the X-axis. The same crank, through the friction wheel, 7, drives the table 8-8, to the left. A strip of paper is fastened to this table, and the pencil, 15, draws a curve in Cartesian coordinates. It will be seen that by means of this mechanism the sine-law abscissas are wiped out, and abscissas proportional to time are substituted.

To transfer ordinates of the oscillogram from the platen to the table, the carriage 9-9, with a crossbar, 10, is used. The carriage can be moved up and down on the rails 12 and 13. The pencil, 15, is attached to the carriage by means of the bracket 14. The stylus, 11, is fastened to the crossbar, 10.

To operate the transcriber, the crank is turned slowly and at the same time the carriage is moved up and down in such a way that the stylus always remains on the curve. The pencil then traces the transformed curve. When many oscillograms are to be transcribed, one person should turn the crank and another operate the carriage.

Determination of Power Loss by Weighing. When power loss is to be evaluated regularly from a large number of oscillograms, the point-by-point method described in the paper may prove to be too tedious. It is necessary to measure a large

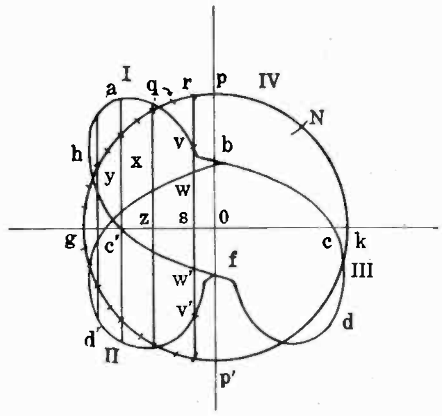

FIG. 2

number of ordinates, multiply each by the sine of an angle, and add the products, keeping the positive and the negative quantities separate. An automatic method of weighing may prove useful in such cases, especially since it enables us to use a much larger number of ordinates with a comparatively small additional required amount of time. The principle of the method is shown in Figs. 2 and 3. For the sake of illustration, we shall assume, with the authors, that it is sufficient to divide each cycle into 20 equal intervals of time, Δt, each corresponding to 18 electrical degrees. Replacing integration approximately by summation, the average power, P, per cycle may be written in the form

$$P = (1/T) \sum_{t=o}^{t=T} i_m \, e_m \, \Delta t$$

where T is the duration of a cycle, and i_m and e_m are the average

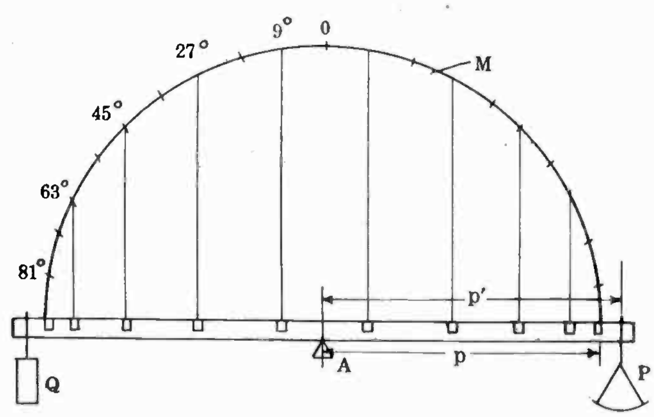

FIG. 3

values of current and voltage during the small interval Δt. In Fig. 2, the curve, $a\ b\ c\ d\ f\ h$, represents a loop obtained experimentally, with sine-law abscissas. The circle, N is drawn with a radius equal to the amplitude of the voltage, $E = O\,g = O\,k$. The circle is divided into 40 equal parts, corresponding to 9 deg. each. Thus, the arc p corresponds to the interval Δt, and r is the middle point of this interval. $O\,s$ is the mean voltage e_m during this interval, and $s\,v$ is the corresponding

1. A. I. E. E. JOURNAL, December 1927, p. 1322.

mean current, i_m. Similarly, the ordinates x, y, etc., mark the middle points of the consecutive intervals Δt. The abscissa $O s = E \sin 9$ deg., the next abscissa $O z = E \sin 27$ deg., etc. Thus, eq. (1) becomes

$$P = (\Delta t / T) \, E \, [_{m1} \sin 9° + i_{m2} \sin 27° + \text{etc.}] \quad (2)$$

Instead of scaling off the ordinates and multiplying them by the sines of the corresponding angles, the simple balance beam, shown in Fig. 3, may be used. It is provided with notches at distances from the center proportional to sin 9 deg., sin 27 deg., etc. The beam is supported in the usual way on a knife edge at the center, has a pan P at one end and a counterweight, Q, at the other end, to balance the pan. Some strip or wire of uniform weight per unit length is provided, so that lengths can be measured by weighing. Let a piece of length, $s\,v$, be cut off and placed in the first notch to the left of A. The turning moment exerted upon the beam will be proportional to i_{m1} sin 9 deg., that is, proportional to the first term within the brackets in eq. (2).

Corresponding strips are placed in the remaining notches. The ordinates in the quadrants I and III of the loop give positive values o: torque (counter-clockwise), and those in quadrants II and IV contribute to the negative torque. Having placed all the strips, the beam is balanced by putting some strip in the pan P. Let the length of this strip be l. If the pan were placed at the distance p from A, corresponding to the radius of the semi-circle M, the length l would rep esent the value of the expression in the brackets. If the pan is at a distance p^1, the corrected value of l, reduced to the arm length p, is $l\ (p^1/p)$. All the quantities in eq. (2) being known, the power P may be readily computed.

The number of strips may be reduced to one-half by re-drawing the parts of the loop in the quadrants III and IV in quadrants I and II, as shown by the curve $b\,c^1\,d^1\,f$. This can be easily done by folding the film along $p\,p^1$. In this case, instead of cutting a piece of strip equal to $s\,v$, and later one corresponding to $s\ v^1$, a piece of length $v\,v^1$ can be cut off at once, covering both positive quadrants I and III. Similarly, a piece of length $w\,w^1$ will tak care of both negative quadrants. Since both strips act on equal lever arms, the net results on the beam is the same as if piece of lengths $v\,w^1$ and $w^1\,v^1$ were placed on the positive side. This procedure of using different pieces on the beam may be used, if it appears to be preferable.

Other Uses of Weighing. A similar method of computation by weighing may be used in other cases when the unknown quantity is of the form

$$Q = a\,x + b\,y + c\,z + \text{etc.} \quad (3)$$

wherein a, b, c, etc., are known constant coefficients, and x, y, z, etc., are some measured quantities. In a balance beam, notches are then made at distances a, b, c, etc. (positive or negative) from the knife-edge support, and strips of paper or metal, or wires of lengths x, y, z, etc., are placed at these lever arms, keeping in mind the sign of each product. The length of wire or strip necessary to balance the beam, multiplied by its distance from the center, will give the value of Q in eq. (3). The following examples may be cited:

(a) In cost estimates, where a, b, c, are unit costs and x, y, z, are quantities of materials,

(b) In computing the voltage drop along a line with branch loads.

The factors a, b, c, may then represent lengths and x, y, z, load currents.[2]

(c) When analyzing an irregular wave into its harmonics, equidistant ordinates are multiplied by the sines of certain angles.[3] By providing a balance somewhat like in Fig. 2, and another with cosine notches, the amplitudes of harmonics can be quickly and accurately determined. Two balance beams are necessary for each harmonic, so that the arrangement would pay only when a large number of waves are to be analyzed.

C. F. Harding: Referring particularly to the reference to the loss due to corona, it may be well to point out that these papers confirm the importance of attacking a problem such as this from many different angles, in many different sections of the country, and on many different transmission lines.

Beginning about the year 1912, and extending through several papers before the Institute, and a number of discussions, results of net losses due to corona on various transmission and experimental lines have been presented by various authors, and compared with the theoretical values, *i. e.*, the empirical equations which have been developed in various laboratories.

In most instances, those losses have compared favorably with the results calculated from the formulas which have been developed by Mr. Peek, and which have been repeated in this paper. That is particularly true for the losses at relatively low voltages, such as those up to and slightly exceeding the critical voltage between wires. If the net loss due to corona calculated by Peek's formula be plotted in kw. as ordinates, and the kilovolts between cables or between one cable and neutral be expressed as abscissas, a parabola results as indicated in the paper. If the actual net loss due to corona be plotted for an experimental line or for a transmission line operating under the same conditions, *i. e.*, the same frequency, density factor, size cables, spacing, etc., this curve checks very closely at low voltages with the quadratic curve. In many instances the test curve was found to be slightly higher in the lower range of voltage, but had considerably lower values of power loss throughout the higher ranges of voltage.

In other words, if we assume that the net corona loss in kw. is equal to some constant multiplied by the square of the difference between impressed voltage and critical voltage, the quadratic law of Peek's formula results. Actual tests show a curve of smaller loss and less slope at the higher voltages; at least on the lines at Purdue University. This would seem to indicate that either this exponent (2) is a little high, or that the critical voltage E_o varies with the voltage E impressed upon the line. Possibly both conditions exist simultaneously. Actual values for the exponent—call this N—have been of the order of 1.55 to 1.7 but always less than the 2 of the quadratic law of Peek.

In the paper presented by the speaker in 1924 at the Pasadena convention, the result of the possible increase of this E_o, *i. e.*, the disruptive voltage of air, because of the formation of the coronal cylinder of greater capacitance, at these higher values of voltage, was suggested. If we consider that this relatively large conducting cylinder of ionized air which has been termed the coronal cylinder does exist about the cable at extra high voltages, in other words, if we take the assumption of the papers presented by Messrs. Peek, Lloyd, and Starr, it is probable that the critical voltage E_o at this point, as the result of the larger capacitance of this larger coronal cylinder, does change materially with these very high voltages impressed between cables. We are dealing with the critical voltage at the surface of the coronal cylinder or some other intermediate point rather than the voltage at the cable itself.

This would seem to indicate that it may be possible, by means of tests on transmission lines where net losses due to corona are determined very accurately from wattmeter measurement in the high-voltage circuit itself, to bring these test relations into conformity with, or conversely, and more appropriately to bring the formula into conformity with the empirical functions established by such tests.

The important feature of this, it seems to me, is the fact that

2. V. Karapetoff, Engineering Mathematics (Wileys), Part V, Chapter II. In the early days of electrical engineering, a German firm used to market a simple balance on which one could "hang amperes" at proper distances and balance them by a weight in the pan. The weights were stamped directly in square millimeters, to indicate the required cross-section of line conductor.

3. V. Karapetoff, Experimental Electrical Engineering, Vol. II, Third Edition, p. 577.

in practically all these tests, made over a long series of years, including a large number of spacings of cables ranging from 18 ft. to 38 ft., with sizes of cables from No. 0 up to 300,000 cir. mils stranded, that the Peek formula is a very conservative one, and that the corona loss actually is considerably less, at these higher voltages, than would be indicated by the calculations. We are on the safe side, therefore, if we design transmission lines in accordance with that formula.

The statement is made, however, in the papers under discussion that the line should not be operated at or above the critical voltage at which corona forms; *i. e.*, under dry-weather conditions. Designing for that voltage means that such a line will operate in many cases with considerable corona formation upon it, as many have noted substations and lines in more or less continuous operation with corona formation. It is important, therefore, to determine both by tests in laboratory and on operating lines just what this difference is between the two curves at the voltages in excess of the critical voltage.

W. F. Davidson: Mr. Lloyd and Mr. Starr described the method they have been using with the cathode ray oscillograph for studying corona formation. A short time ago I tried a similar tube in studying the distortion of current through a cable sample, with the idea of determining whether there was corona formation.

We used basically somewhat the ideas suggested by Professor

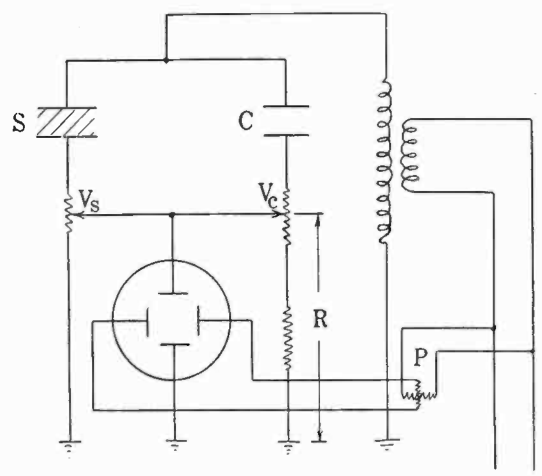

Fig. 4

Karapetoff of eliminating the straight capacity component of the charging current through the samples.

The supply transformer in this case was grounded at one end; the sample S connected as indicated in the accompanying Fig. 4 and brought down through a small resistance to ground, the no-loss air condenser C connected in parallel through a corresponding resistance, in fact, two resistances. The cathode ray is connected with one plate so as to take the drop $V_s - V_c$ giving a deflection proportional to watt-component current through the sample in the test, now, by controlling the total resistance R we had the possibility of shifting the base position of the current through the air condenser. That was sometimes of value and of help.

The other component was obtained in two different ways, in the first work, much as Mr. Lloyd has described, by taking the potential applied to the transformer. We found considerable difficulty in using our particular tube, however, because neither axis was straight; that is, the pattern instead of being straight, gave two rather distorted curves.

In order to overcome that difficulty, we made a calibration in the direction of abscissa, corresponding to these deflections, then we arranged our time curve. These were controlled by a phase shifter P, that was supplied from the same primary as the transformer. The cyclogram would then appear in various forms, and we would shift the thing around, changing the phase around, changing the phase shifter until the particular point we were interested in was on the central axis and then we scaled this point.

There were two operators, one reading the phase shifts and the other reading the ordinates, and it took only about a minute to get a complete record. We were rather disappointed in some of the results because although they were very satisfactory in a qualitative way, we were not successful in getting them in a quantitative way. Perhaps we could do better with a tube that did not have such a badly distorted pattern.

J. Ryan: (communicated after adjournment) The results obtained by the authors of these corona papers and their corresponding conclusions will help greatly to establish a better understanding of the nature of corona. During the past four years by independent effort we have arrived at substantially the same results and corresponding conclusions. Our studies during the past year were mostly concerned with the mobility and make-up of the space charge and the manner in which its portions having constant and alternating polarities function.

Three methods have been used successfully for the cyclic study of corona by means of the cathode ray tube. In the first of these the ray-pointer is deflected electromagnetically.[4,5] In the second the deflections are produced electrostatically so as to yield quadrature ray-pointer deflections proportional to the voltage and to the rate of increase or decrease of the current in instantaneous relation. Thus the ray-pointer develops areas proportional to the time-integral of the volt-amperes or energy.[6] The third has been used by Mr. Peek and his co-workers. In it the ray-pointer is also actuated electrostatically and yields deflections proportional to simultaneous values of voltage and current. The first and third methods produce volt-ampere cyclograms and the second energy cyclograms.

The first avoids the necessity of using electrostatic deflectors mounted within the cathode ray tubes but requires a great variety of deflector current coils and potential-circuit resistors, some of which are expensive. Electrostatic deflectors mounted within the cathode ray tube are used in the second and third methods. Externally mounted electrostatic deflectors are not satisfactory because of the bound charges that assemble on the inner walls of the tube opposite the deflectors. We have used the three methods and recommend the use of the second and third. The choice depends upon the character of work to be done. Occasionally both are required in the same undertaking. Because a condenser must be used in the current circuit of the energy cyclograph it cannot be used when more than a mere trace of rectified current is present. Such current when small enough may be successfully bypassed with a "leak" of the proper value. Again when the observation of sudden changes of current or e. m. f. are to be made the energy cyclograph being a volt-ampere-time integrator, is less helpful and the electrostatically operated voltage-current cyclograph should then be used.

Following the recognition of the presence of the space charge that surrounds a conductor in corona it was found that the corona loss equals the energy that is dissipated in the space-charge condenser at unity power factor subjected to the voltage in excess of the critical voltage, *i. e.*, voltage above the lowest voltage that will sustain a fixed brush pattern.[7] Thereafter the capacitance and position of the space-charge condenser were studied with the energy cyclograph, using cylindrical barriers around the conductor to fix the radius within which the space charge is confined.[8] These studies were then followed by others

4. *The Cathode Ray Alternating-Current Wave Indicator*, H. J. Ryan, A. I. E. E. Trans., Vol. XXII, 1903, p. 539.

5. *The Conductivity of the Atmosphere at High Voltages*, H. J. Ryan, A. I. E. E. Trans., Vol. XXIII, 1904, p. 101.

6. *A Power Diagram Indicator for High-Tension Circuits*, H. J. Ryan, A. I. E. E. Trans., Vol. XXX, 1911, p. 1089.

7. *The Hysteresis Character of Corona Formation*, H. J. Ryan and H. H. Henline, A. I. E. E. Trans., Vol. XLIII, 1924, p. 1118.

8. *On the Nature of Corona Loss*, C. T. Hesselmeyer and J. K. Kostko, A. I. E. E. Trans., Vol. XLIV, 1925, p. 1016.

to determine the central radial position of the alternating portion of the space charge by means of the potential exploring wire.[9]

During the past year my co-workers, J. C. Carroll and J. T. Lusignam, Jr., have tudied the cyclic character of the ion-content of the space charge. One of the many purposes of the study was to add to the background of knowledge required to improve interpretation of the observations made with the potential exploration wire and to understand the function of the constant-polarity portion of the space-charge function in alternating corona formation. The corresponding results and conclusions are being embodied in a paper soon to be presented to the Institute.[10]

It has long since been known that the values of positive and negative corona-forming voltages differ. Dependent upon the particular conditions the difference varies from zero to a considerable fraction of either polarity of the critical voltage. The rectified portion of the space charge in alternating corona is caused by this difference. For example if the critical voltage is greater when negative than when positive, the magnitudes of the corresponding space charges will have to be in reciprocal relation. When the conductor requires a higher negative than positive corona-forming voltage there will be formed and maintained the larger space charge from the positive to the negative voltage crests; and correspondingly the smaller space charge from the negative to the positive voltage crests. This gives rise to the phenomenon of "rectification" that is often witnessed in the study of corona. The portion of the space charge having constant polarity will increase the strength of the field attached to the conductor as the voltage approaches one crest and will diminish it as the voltage approaches the other crest. Thus the differences of the positive and negative critical fields and their corresponding initial voltages from their averages are compensated for by the presence of the constant-polarity portion of the space charge. It follows, therefore, that the initial value of the cyclic critical voltage must be as much below the value of the crest voltage as it is above the value of the subsequent critical voltage that starts corona formation in the succeeding cycles and that the positive and negative critical voltages must be equal. From the nature of things here set forth power-transmission conductors operated in corona will display constant polarity high potential phenomena to a limited extent and the direct currents thus set up in ionic mobility from the conductors through the air and over the insulators to earth are not likely to develop effects of much practical importance.

The model of corona given by Mr. Peek is helpful for gaining an understanding of the essential features of corona. The theory of this model as developed in our studies was given by Messrs. Hesselmeyer and Kostko in connection with Fig. 14 of their paper on the Nature of Corona.[8] Guided by this theory we made up in the summer of 1926 a model such as described by Mr. Peek, using a pair of Leyden jars with a spark-gap in parallel with one of them. It produced artificial corona cyclograms quite like cyclogram No. 4 in Fig. 6 of the Hesselmeyer-Kostko paper. It gave the oblique straight sided parallelograms that theory called for. Of course it did not repeat the minor departures that are witnessed in actual corona wherein the space charges are mobile. See for example the group of cyclograms in Fig. 10 of the same paper taken from a single-phase line mounted in the open to which corona forming voltage was applied.

All in this group conform liberally but not exactly to the oblique parallelogram wherein the slopes of the sides and ends determine the values of the capacitances of the conductors and space charges, and wherein the departures from the straight sided oblique parallelograms are measures of the effects due to causes that are not included, necessarily so, in the incomplete theory, such as conduction (thermal dissociation) and ionic mobility actions that Mr. Peek properly sums up in his paper by the phrase "corona arcs."

As a result of these studies we are convinced that Mr. Peek is right in his conclusion that the power-loss-voltage relation in full corona formation is a rational quadratic because of the space charge condenser. He is also right in recommending that care be used to avoid mechanical injury to the surface of the conductor. One should note, however, that losses due to local corona are greatly dependent upon the uniformity of the physical-chemical regularity. Greatest regularity is required to produce minimum local corona loss, since the maintenance of a smooth, polished conductor is not feasible. We have found this to be so for local corona loss when the mechanical irregularities or roughness of the surface of the transmission conductor have been carefully avoided. The local corona losses are likewise dependent to important extents upon the humidity in the air and the crest and effective values of the voltages. Because of the prominent part that the space charge condenser takes in corona formation one must expect the cyclic loss to be dependent upon the crest value of the voltage; again because the space charge is mobile its containing condensers do not have fixed value, and one must expect the cyclic loss to be dependent also upon the effective value of the voltage.

The local corona studies here referred to were made by our graduate students Messrs. Drodjin and Wiedeman and will be embodied in a paper that they will offer for publication at an early date. Local coronas are simply scattered brushes. In the local corona loss-voltage relation the numbers and positions of the brushes are large factors, which in turn depend upon the smaller factors just specified all of which in the full corona loss-voltage relation are of little or no importance. Local corona is an instability complex and much systematic study under all relevant conditions will have to be promulgated to know what high-voltage conductor diameters, and insulator hardware forms to adopt to meet all requirements.

E. C. Starr: Professor Karapetoff and Mr. Davidson have spoken of neutralizing the charging component of the current wave. We considered that, inasmuch as the portion of the figure that is said to represent charging current is not, strictly speaking, only charging current as based upon the capacitance of the wire itself, but charging current based upon the capacitance of the wire as affected by the motion of the space charge, we thought it best to leave it all in to show the whole wave. That suggestion, however, would allow us to show only what the corona does and under certain conditions would be useful.

Mr. Davidson spoke of his tube giving axes that were crooked. We found that the condition would be brought about if the source of the magnetic field used to neutralize the effects of the earth's magnetic field was placed too near the tube. It is necessary to place the source at a distance of 3 or 4 ft. from the tube in order to obtain a uniform field throughout the tube and thus eliminate distortion of the axes. It is possible that this was the source of Mr. Davidson's trouble.

Professor Karapetoff's mechanical devices are very clever, and should be useful where the work is to be done on a large scale.

F. W. Peek, Jr.: It is very difficult to estimate corona loss on practical lines with great accuracy because it is very difficult to determine the conditions along a long line; there are so many variables.

If a wire about an inch in diameter is taken and the loss is measured up to several million volts, it will be found that, at first, the quadratic law obtains up to a very high voltage. Finally, at some point the loss begins to fall below the original quadratic. It eventually follows another quadratic. The new curve, if extended, will be found to cut the axis at a new critical corona voltage. At the point where the deviation occurs, the appearance of the corona discharge changes. Great "cartwheels" form around the conductors. These cartwheels sepa-

9. *The Space Charge that Surrounds a Conductor in Corona at 60 Cycles,* J. S. Carroll and H. J. Ryan, A. I. E. E. Jl., November, 1926, p. 1136.

10. *The Space Charge That Surrounds a Conductor in Corona,* A. I. E. E. Pacific Coast Convention, Del Monte, Calif., September 14, 1927.

rate, act as shields, and change the whole electrostatic field. I do not think it is a practical condition because this deviation from the quadratic occurs at many times the operating voltage for the conductors. It is amazing, in fact, that any law is followed at these high voltages.

It seems to me that operation should be below the critical voltage for fair weather. It is practically impossible to eliminate all loss in wet weather. It is thus important to determine the irregularity factors for various types and sizes of weathered conductors. This offers a good field for investigation.

RECENT INVESTIGATIONS OF TRANSMISSION-LINE OPERATION[1]

(Hemstreet)

Detroit, Michigan, June 21, 1927

G. H. Doan: The top wire of our 120-kv. lines is very much more susceptible to flashover and damage than any of the others. We had concrete evidence of that last year when a lightning stroke hit directly on a radio tower which was very close to the high-voltage lines. A klydonograph about a quarter of a mile away showed that there was about 5 times normal potential on the top wire, 3.3 on the middle, and 2.7 on the bottom. That, however, did not cause flashover, and did not, of course, cause opening of the oil circuit breaker.

This is further borne out by the position of broken insulators. The record for last year shows that 77 per cent of the insulator flashovers were on the top wire; 19.4 per cent on the middle, and only 2.8 per cent on the bottom wire.

We have also some very interesting data as to the good of ground wires. We started our 120-kv. system, and ran it during the season of 1925 without a ground wire on that portion which was working. During that season, we had 114 automatic switch openings. During the winter it was equipped with a ground wire, and the following year, (in 1926), we had 7 openings, which is a reduction in switch openings of practically 94 per cent. The storms which passed over that area decreased 47 per cent, so that there is a possibility that the storms which we had were not so severe, and we certainly know we didn't have as many of them; but it seems that the ground wire had afforded quite a little protection.

Mr. Hemstreet points out that in dry sandy country he has experienced many more flashovers than in the lower districts. We also find that is true. In one particular section, where the land is rather high, rolling, and sandy, and the ground resistance rather high, we have experienced, I think, about 50 per cent of the flashovers of which I spoke.

R. L. McCoy: Mr. Hemstreet has pointed out the advantage of the longer-spaced suspension insulator. It has always been the policy of the Locke Insulator Corporation to recommend the use of a relatively long-spaced suspension unit.

A few years ago the major insulator problem was that of preventing puncture of the units by the voltages impressed upon them. That problem is now well in hand and the major problem is to prevent lightning flashovers as much as is possible and as is feasibly economical and to prevent the attending damage.

Researches which have been made by Mr. F. W. Peek have shown us the nature of the voltage impressed upon line insulators by lightning.

It is desirable that we study the action and characteristics of line insulators under these voltages. The lightning generator has given us an opportunity to make these studies. A very careful investigation has been made with lightning. We find that with all types of suspension insulators regardless of the spacing, cascading occurs. This fact is borne out by Mr. Hemstreet's experience.

The reason for this is found in the fact that the distribution of the voltage impressed on the various units of the insulator string is not uniform. The line unit bearing the brunt of the surge flashes over before the remaining insulators flash over. This, then, makes the second unit from the line at the same potential as the line and it flashes over. The flashover therefore is progressive, one unit at a time, with the arc striking to each insulator cap. The power arc follows the path of the lightning arc and starts as a pure cascade. This accounts for a large number of cases where we find cascading on all of the units of an insulator string when it was flashed over by lightning. Incidentally, we find this on insulators of all spacings.

Our problem then is to find a way of using the insulation in the insulator to the best advantage to produce high flashover values which will reduce number of flashovers, and prevent cascading of the lightning arc. Recent studies with lightning show no appreciable difference in cascading between insulators of minimum spacing and insulators of approximately 6-in. spacing for a 10-in. disk.

Flashover values are directly in proportion to the string length. The longer spacing is obviously advantageous from this point of view.

Mr. Hemstreet states further that the power arc has a strong tendency to blow away from the insulator if the initial cascade caused by lightning can be prevented. The grading shield offers a means of doing exactly this. The reason for this is that the grading shield reduces the voltage across the line unit and makes the voltage duty upon each unit more nearly uniform and when the flashover occurs it is a complete flashover from ring to ring, or, ring to horn, and the arc is started several inches away from the insulator. The chances of its doing damage therefore are much reduced.

Recent investigations show that the grading shield can be designed to prevent cascading of the lightning arc, and also because of better field conditions established, give an increase of from 15 to 20 per cent in the flashover value over that of the unprotected string. This is interesting, because on 132,000 volts or above we are near the point where the insulators have a flashover value equal to the voltage imposed upon them. An increase, therefore, of a few per cent in the flashover value may reduce very materially the number of flashovers.

A. O. Austin: In view of some of the points raised by Mr. Hemstreet's paper, it would seem that some recent theory and investigation should be of interest.

Flashovers on transmission lines are reduced by raising the effective flashover voltage of the insulator between conductor and ground, or by reducing the abnormal potential on the conductor. In addition to these two methods or factors, a new method has been developed which I have called the counterpotential method.

In this discussion I wish to call particular attention to the last two methods.

The new method eliminates the danger of burning and permits taking advantage of the very high flashover values for lightning possessed by wood structures, to which Mr. Hemstreet called attention.

Reduction in the effective height of the conductor and the installation of ground wires are two factors which can be used to advantage for increasing the ratio of flashover voltage to surge potential for steel tower lines. Recent improvement in the theory of the ground wire gives a working knowledge of the various factors governing its functioning so that it can be evaluated for any installation. In applying the ground wire, to obtain best results, it is necessary that we have a knowledge of just how it functions.

A charged cloud over the power conductor will induce a charge on the conductor. This charge is a bound charge and will be the same for a conductor or a ground wire in the same position. Following the discharge of the cloud, the bound charge will be released and cause the potential of the conductor, if insulated, to rise. This rise in potential is of great importance and a study of

1. A. I. E. E. Journal, November, 1927, p. 1211.

the factors has been made. Before the cloud discharges, the conductor may be regarded as forming a condenser with the cloud. Following the discharge the conductor forms a condenser with ground or objects of lower potential such as a ground wire.

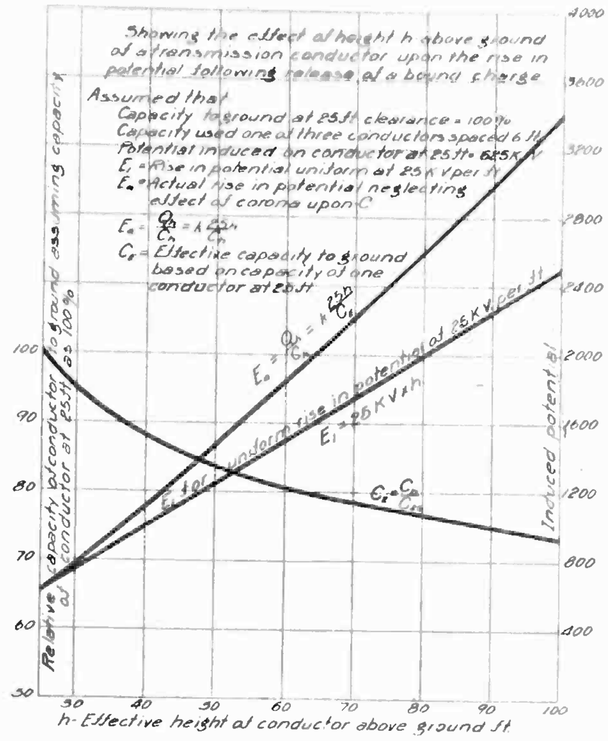

FIG. 1

In general, the potential on a conductor may be said to vary as Q/C where Q is the charge and C the effective capacitance of the conductor to ground. It therefore follows that factors which affect Q and C must be given consideration in determining the rise in potential for a given gradient.

The charge Q will increase directly with the height in a field of uniform gradient while the value of C is reduced with the

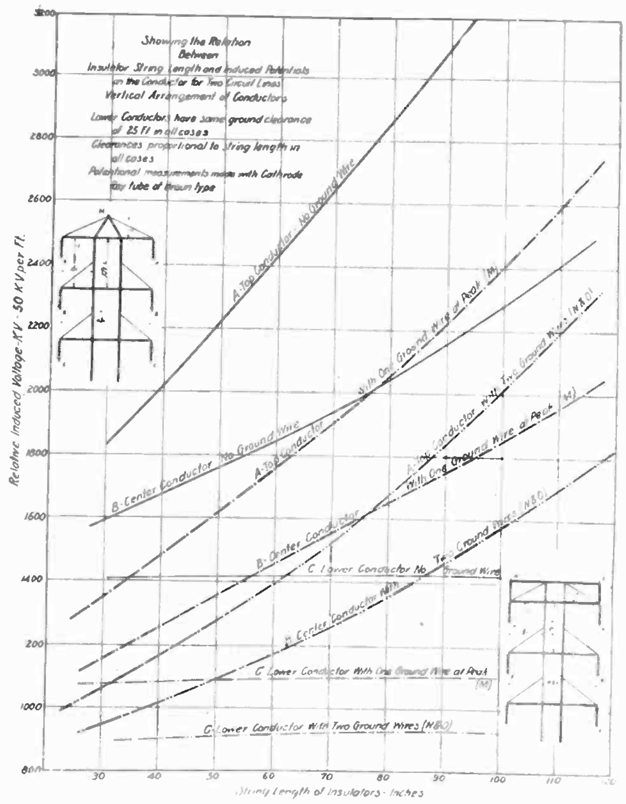

FIG. 2

height of the conductor. It therefore follows that the induced potential Q/C will increase at a more rapid rate for greater heights of conductor. This is shown in Fig. 1 herewith.

Bringing the power conductors nearer together reduces Q, but this advantage is partially offset since it also reduces C. Where a ground wire is used to increase C, it is evident, however, that close spacing reduces Q and increases C. Since the ground wire functions by increasing C rather than by reducing Q, its location and number should take this into account rather than its location for screening.

By the use of a cathode ray oscillograph of the Braun-tube type it is possible to measure induced voltages on model lines with ease.

Fig. 2 shows a study based on string length. In this study the induced voltage on the conductors of a two-circuit line is shown as measured by this method. It will be seen that the induced potential rises very rapidly with the increase in string length.

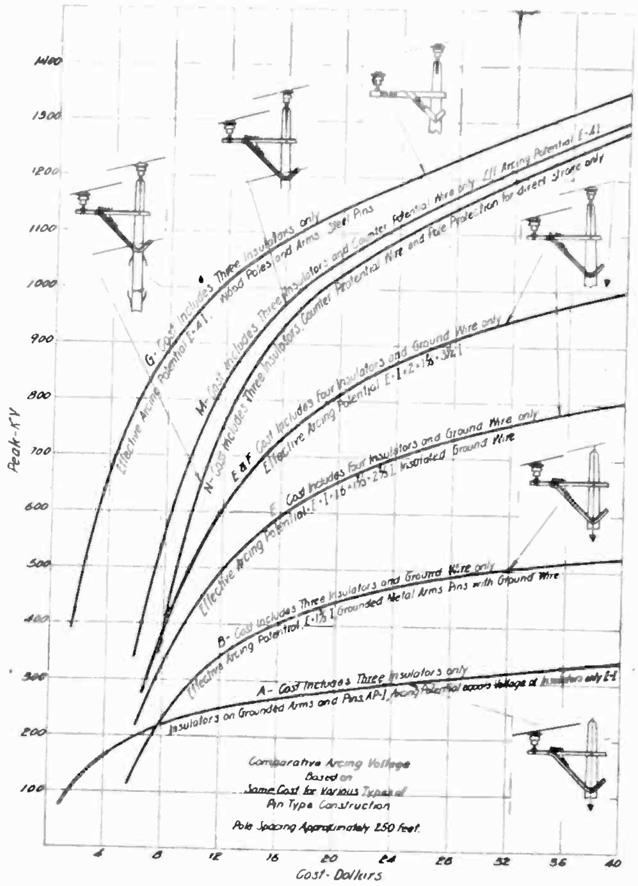

FIG. 3

Increasing the length of a string 2 ft. not only spreads the conductors but raises the top conductor at least 10 ft. Where the electrical gradient set up by the cloud is steep, it is seen that increasing the string length may result in more flashovers unless the height of the conductors is kept down or the factor C increased by placing ground wires at other points than at the peak of the tower.

In wood-pole structures the problem is different. The installation of a ground wire may eliminate insulation several times that of the insulator. It therefore follows that where a ground wire is usually an advantage on a steel-tower line, it almost invariably increases line trouble when applied to a wood-pole line which has effective insulation. The reasons for this are clearly shown in Figs. 3 and 4. It will also be noted that the insulated ground wire and the counter-potential wire have great advantages over the ground wire for preventing flashovers induced by lightning. While the insulated ground wire cannot be used where unbalanced leakage is likely to burn the pole, the counter-potential wire takes care of this and also facilitates the operation of relays.

The counter-potential wire may be very effective when applied to a steel tower having an insulating zone. In operation, the release of a bound charge raises the potential of the counter-potential wire and connected tower top or cross arm coincident with the rise in potential on the power conductor. Since the potential of the insulator support is raised, the stress tending to flash the insulator or conductor will be reduced by the amount that the tower top is raised by the counter-potential or charging wire.

By properly spacing the height of the counter-potential wire it is possible to control the potential of the support adjacent to the insulator so that the flashover voltage of the insulating zone of the tower can be added to that of the insulator, giving exceedingly high flashover values for what would otherwise be a low or moderate flashover voltage system. In addition to giving exceedingly high flashover values it makes it possible to effect very material economies due to the closer spacing of conductors.

Since the danger of burning of the insulated section is removed by the counter-potential wire and relay operation is insured, this new method of line construction has material possibilities which may be applied for improving old lines as well as being adapted for new construction where it is desired to reduce or eliminate flashovers.

It is also possible to use the construction in conjunction with a ground wire. It is, however, necessary to place the ground wire below the insulated zone or to insulate it from the upper section of the structure.

Mr. Hemstreet raises the question as to the effect of ground resistance on flashovers. From a consideration of the counter-potential wire it is apparent that if the effective height of the conductor has not been increased, a high ground resistance may permit the structure to be charged momentarily. This will tend to reduce the stress tending to flash the insulator so that the danger of arcing would really be less. If the nature of the ground, however, is such that the conductors have a very high effective height, this may more than offset the high ground resistance and result in increased flashovers.

Impact tests made recently on long strings with much larger amounts of energy than have heretofore been available, show that many insulator strings or arrangements which it has been assumed (from tests on short strings), would arc free, frequently cascade. These tests apparently give results similar to those shown in the examination carried out by Mr. Hemstreet. It is hoped that an oscillograph record of the flashovers on test will throw much light on the nature of some of the various types of flashovers noted on the system.

While the path of an arc may be determined at the expense of flashover voltage, once formed further control of the arc is lost, hence operation can best be improved by increasing the effective ratio of flashover voltage to the surge voltage. With a better understanding of the various factors it is now possible to consider the cost of the line per mile on a flashover basis as well as on a mechanical basis. When this is carried out, great improvement in the elimination of flashovers will result.

W. L. Lloyd: I am glad to note that the operating results have checked so well Mr. Peek's laboratory tests, in that the lightning voltage is directly dependent upon the height of the phase wire above conducting soil.

With wet soils, the greatest number of flashovers should occur on the upper conductor. I understood Mr. Hemstreet to say that actually 85 per cent of the flashovers occurred on the upper conductor under such conditions, whereas the lower conductor was practically immune from lightning.

With dry soils, where the conducting level is perhaps far below the ground level, and the percentage difference between the effective heights of the three vertically spaced conductors is greatly diminished, there should be more flashovers; but a more even distribution in the number of flashovers should be expected. This is in accordance with the operating results reported by Mr. Hemstreet.

On important lines, we recommend the ground wire to reduce the number of flashovers and the grading shield to eliminate damage to the insulator string or line conductor in the case of those fewer number of flashovers which remain.

I am particularly interested in the klydonograph surge-recorder measurements on this system, and am glad to note that these measurements check so well with our estimates based upon tests in the laboratory with Mr. Peek's 2,000,000-volt artificial-lightning generator.

J. G. Hemstreet: It is gratifying and encouraging to know that the representatives of operating and manufacturing companies and those working in the laboratories on this same problem are in agreement on practically all of the various points that have been brought out.

It is evident that a great deal of the mystery surrounding the transient conditions existing in transmission systems is being cleared away and the knowledge that has been gained of these conditions from experience in the field and laboratory tests and investigations may enable us to provide high-voltage transmission lines that will be very free from trouble due to lightning.

Mr. Austin has introduced somewhat of an innovation in the counter-potential method of preventing insulator flashovers

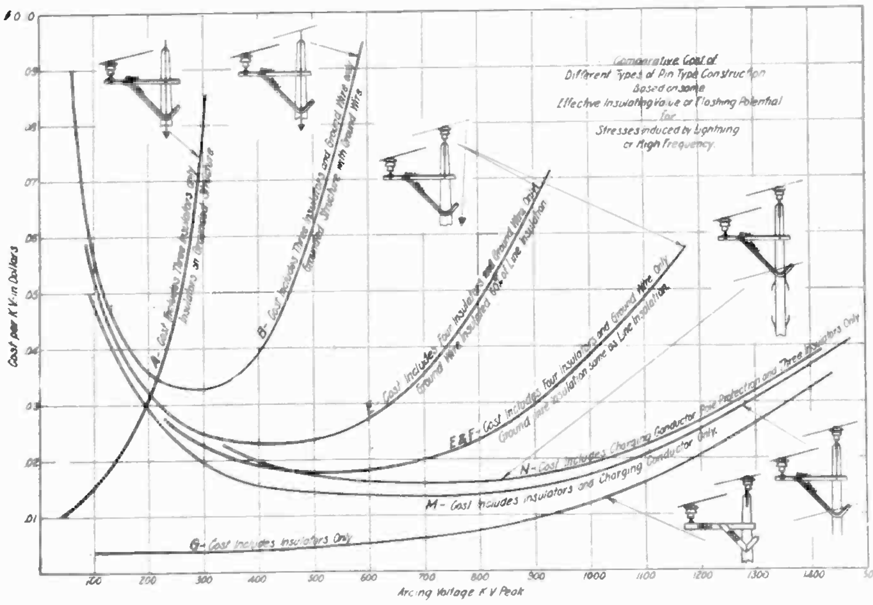

FIG. 4

Results of experience in the field will be awaited with interest to determine if this method is as effective as a ground wire. One of the benefits obtained from the use of ground wire is the protection to the station equipment by holding down the transient voltages in the transmission line. The counter-potential method evidently does not accomplish this purpose, but possibly a combination of the two using ground wire near the stations might accomplish the desired results.

Discussion at Pittsfield Meeting

QUANTITATIVE DETERMINATION OF RADIO-RECEIVER PERFORMANCE[1]

(Oakley)

Pittsfield, Mass., May 25, 1927

A. L. Cook: I think it is a decided indication of progress in the development of sets when the manufacturers begin to test their complete sets and publish results of these tests.

I wish to ask particularly about the curves on the fifth page of the paper showing the quality of reproduction of a certain receiver. I wish to ask does the method of testing used really tell whether or not the set has good quality of reproduction?

As I understand it, the method is based upon the measurement of voltage amplification at different audio frequencies and I wish to ask if this is a true measure of the quality? That is, if this were a straight line parallel to the horizontal axis, would this represent a perfect set?

I believe that most of the energy in a complex note is in the lower frequencies, and it would seem to me that the energy amplification would be more important than the voltage amplification. I should like to ask Mr. Oakley, therefore, if an indication of the relative energy amplification at different frequencies would not be a more exact representation of the quality than is the voltage amplification?

B. V. K. French: I should like to ask Mr. Oakley about the amount of error in the attenuator used. The attenuator was described, I believe, by A. W. Hull, in the *Physical Review* of 1925, and I wonder if any errors have been calculated?

Another question I should like to ask is, how is the percentage modulation measured on the oscillator defined, and how can we all reach the same agreement on the necessary percentage modulation to simulate broadcast reception conditions?

H. D. Oakley: The point about the quality curves of receivers is at present quite a disputed one. It has already been proposed to measure the power delivered to a loudspeaker rather than the voltage across it. But even in this case, the designers of loudspeakers are not prepared to say whether a definite relation exists between the power supplied to a loudspeaker and the sound received by the ear of the listener. Variations in room conditions cause variation in the sound received by the ear. If we could measure the sound pressure at the microphone of the transmitter and the sound pressure at the ear of the listener, then a true representation of quality for a particular set of conditions could be made. Because so many variables do exist, and because it is more convenient to measure voltage than power delivered to a loudspeaker, our quality curves are plotted in terms of voltage against frequency. We depend a great deal upon past experience in interpreting the picture presented to us by the quality curves.

The other point brought up was concerning the type of inductor used in making the measurements. Calculation of inductance involves a term which is the log of the ratio of the radius of the cylindrical shell to the radius of the rod inside the shell. Slight errors in determining the magnitudes of these two radii will cause a very slight error in the calculated value of inductance. There are two other sources of error. (1) The point at which the rod enters the end plate is grounded. Consequently there may be some current flowing from the point through ground and back into the circuit again. So calculations based upon the assumption that all the current flowing in the rod return through the shell may be slightly in error. And (2) the electric field about the shell will induce voltages in the receiver in addition to those obtained from the tap to which the receiver is connected. This error has been eliminated by enclosing the inductor in a shield. Measurements on the inductance show that it is within 4 per cent of calculated values.

The degree of modulation of the current supplied by the oscillator is expressed by the ratio

$$\frac{A - B}{A + B} \times 100$$

where A is the maximum and B the minimum amplitude of the modulated current. For 50 per cent modulation, A would be three times B. No single value of percentage modulation can simulate broadcast-reception conditions, since the percentage modulation of a broadcast transmitter is continually changing and may be any value from zero to distressing over-modulation. But the audio-frequency output of a properly designed receiver should vary directly with the degree of modulation and for measurement purposes a reasonable value should be satisfactory. 50 per cent modulation was used by us, but there is at least a tentative agreement now to use 30 per cent for all receiver measurements.

1. A. I. E. E. Journal, May, 1927, p. 487.

ELECTROLYTIC CORROSION MEASURES

The Bureau of Standards has recently announced the development of an instrument known as the "earth current meter" which measures corrosion of underground structures. In connection with this announcement it is stated that the determination of the seriousness of corrosion of underground structures due to stray electric currents has been difficult and the results unsatisfactory because there has been no simple method of measuring the amount of stray current at the point where electrolysis is suspected. For this reason, engineers of the Bureau have endeavored to develop an instrument which will indicate directly the strength of the current in the earth at a given point. It works upon the theory that the rate of corrosion is directly proportional to the strength of current flowing from a structure. Such an instrument would indicate directly whether the structure under test was in danger from electrolysis. The instrument is described in detail in technical paper No. 351, which also describes the various ways in which it may be used to determine electrolysis conditions.

ILLUMINATION ITEMS

By Committee on Production and Application of Light

NEW MAZDA STREET RAILWAY CUTOUT LAMPS

It has been common practise to use five lamps in series in street railway lighting service where line voltages run about 550 or 600 volts. The lamps regularly used in such service have heretofore been of the straight-filament, vacuum type, rated in wattages 23, 36, 56 and 94 but otherwise similar to the old type of lamps used for multiple lighting service. Gas-filled lamps of ordinary construction cannot be used satisfactorily in series on the high line voltages used in street railway service. The chief cause for unsatisfactory operation is the maintaining of the arc in case the filament is broken while burning. The surrounding gases hold it in a persistent manner due to the high voltage back of it, and eventually the arc becomes destructive.

A low-voltage Mazda C lamp has been developed which is strong mechanically and which incorporates within the lamp itself a cutout device that enables the advantages of the higher efficiency gas-filled lamp to be attained in street railway lighting service.

In case the filament in one of these cutout lamps is broken while the lamp is burning, the subsequent arc maintained as usual in the gaseous atmosphere travels up the lead-in wires inside the lamp until it reaches a special device which short-circuits the lamp and extinguishes the arc. If the filament should be broken while unlighted, the cutout device in the lead-in wires will break down electrically as soon as the circuit voltage is applied.

In either case the circuit through the lamp which has failed is maintained or restored and the lamps in series with it remain lighted, dividing among themselves the voltage which had been applied across the lamp which has been short circuited.

If five lamps are used in series, the short-circuiting of one would increase the voltage applied to each of the other four individuals by 25 per cent. This would place a considerable over-voltage strain on the four remaining lamps and unless the defective lamp were immediately replaced, might lead to their subsequent burnout in rapid succession. By increasing the number of lamps in one series circuit, the short-circuiting of any one of them throws less strain on those remaining. Fortunately, several five-lamp circuits are ordinarily required to light a car. It has been found that if eighteen or more lamps are operated in series the failure (and consequent short-circuiting by the automatic cutout) of any one lamp will not increase the voltage on the remaining lamps by an amount that is objectionable during the short period that normally elapses until the lamp is replaced.

The new gas-filled cutout lamps for street railway service are therefore designed to operate at about 30 volts, so that in ordinary cases from 18 to 22 lamps can be operated in one series on the line voltages ordinarily used in street railway service.

The lamps are made in two current capacities, 1.0 and 1.6 amperes, which, at 30 volts, make the wattages 30 and 48 respectively. The 1.0-ampere lamp is supplied in the A-19 bulb of the same over-all dimensions as the standard 25-watt 115-volt inside frosted lamp. The 1.6-ampere lamp is made in the A-21 bulb such as is used for the regular 40-watt 115-volt inside frosted lamps.

The 1.0-ampere lamp has a light output of approximately 360 lumens and the 1.6-ampere lamp gives 648 lumens. The initial efficiencies of the new Mazda C lamps are 12.0 and 13.5 lumens per watt. These efficiencies are considerably higher than those of the older Mazda B lamps for street railway service, which ran from about 8.8 lumens per watt for the 23-watt size to 9.9 for the 56-watt lamp.

Not only is the initial efficiency of the Mazda C Street Railway cutout lamps considerably higher than that of the vacuum lamps, but they will maintain their initial light output much better throughout life. The average mean lumens of these lamps will be only about 5 per cent below the initial values (because they are gas-filled), whereas in the case of the corresponding vacuum lamps, the average light output will be about 15 per cent less than the initial value. On the basis of average light output the new lamps will therefore deliver 40 or 50 per cent more lumens per watt than the vacuum type lamps.

The new cutout Mazda C lamps are supplied in inside frosted bulbs.

The filaments in the cutout lamps, being of low voltage and of fairly large current capacity, are relatively short and of large diameter so that the lamps are mechanically strong and are particularly well suited to street railway service. It is well know that a large proportion of failures of the old style lamps in street railway service was due to mechanical breakage.

A short-circuiting socket has been developed for use with these lamps which permits a lamp to be removed and replaced without extinguishing the others in series.

In a scientific address in Chicago, Oct. 11 on "Color Temperature Classification of Natural and Artificial Illuminants," Norman Macbeth president of the Illuminating Engineering Society discussed the use of the phrase "just like daylight" which he said was so greatly overworked by lighting apparatus advertisers. The phrase is more than 100 years old, he stated, adding that it was first used in Baltimore to advertise the first flame burner when gas lighting was brought to America. Later, he said, it was applied to the coal oil or kerosene lamp, the Edison carbon filament lamp, arc lamps and gas mantles.

Mr. Macbeth devoted the closing paragraphs of his paper to a discussion of color discrimination. A book is now on the press, he said, that will illustrate and name 6000 colors.

The difficulties surrounding accurate color discrimination and the importance of working out reliable methods were presented and recommended for further research.

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1928 Winter Convention Promises Timely Program

Many live topics will be on the program for the coming Winter Convention of the Institute, to be held in New York City, February 13-17, 1928. A technical program has already been tentatively laid out and it includes such subjects as operation of interconnected power systems, protective and control systems, automatic substations, arc welding, electrophysics, communication, and electrical machinery.

Plans have also been made for the other features including the annual midwinter dinner-dance, a smoker, and various inspection trips.

One evening will be devoted to the presentation of the John Fritz Medal and the Edison Medal.

The arrangements for the meeting are being made by a general convention committee as follows: G. L. Knight, Chairman; J. B. Bassett, H. P. Charlesworth, H. C. Dean, H. W. Drake, W. S. Gorsuch, H. A. Kidder, E. B. Meyer, L. W. W. Morrow, and R. H. Tapscott.

Fall Meeting of Affili ted Engineering Society Sections of Virginia

The annual fall meeting of the Affiliated Engineering Society Sections of Virginia, consisting of the Virginia Sections of the American Society of Mechanical Engineers and American Society of Civil Engineers, and the Southern Virginia Section of the A. I. E. E., was held November 11-12, at the University of Virginia, Charlottesville.

FRIDAY AFTERNOON'S SESSION

The first session was held at 2:30 p. m. on Friday in the main auditorium of the Cobb Chemical Laboratory, with Mr. F. P. Turner, President of the Virginia Section A. S. C. E., presiding.

A brief address of welcome was delivered by E. A. Alderman, President of the University of Virginia, in which he placed great emphasis upon the importance of engineering and said that engineers are really the architects of modern civilization.

After a brief response by Mr. Turner, the following program was presented:

Water and Power Resources of Virginia and Their Proposed Development, by Mr. F. H. Newell, Washington, D. C., President of the Research Service, Inc. Illustrated with lantern slides.

Safety in Engineering, by Mr. G. E. Sanford, Schenectady, N. Y., Safety Engineer, General Electric Company, and Vice-President in charge of Engineering, National Safety Council. Illustrated with lantern slides.

The Beggs Deformeter, by Mr. E. W. Saunders, Jr., Associate Professor of Mathematics, University of Virginia. Illustrated with figures and demonstration of equipment.

After br ef remarks by Dean J. L. Newcomb of the Department of Engineering, University of Virginia, this session was closed.

FRIDAY EVENING SESSION

At 7:00 p. m. Friday evening an informal dinner was held at the Monticello Hotel in Charlottesville, followed by an address on "The Engineer as a Publicist" by W. M. Thornton, Professor of Applied Mathematics, University of Virginia, and former Dean of the Department of Engineering. Professor W. S. Rodman, Chairman, Southern Virginia Section, A. I. E. E., presided.

Following adjournment of the principal meeting, separate business meetings of the three Sections were held. Officers and members of the Southern Virginia Section of the Institute and guests discussed the Sections and Branch conferences held at Detroit in June, as well as other activities of Districts, Sections, and Branches. Much interest was shown in the recent developments to make Institute activities available to a larger portion of the membership.

Those who were present on Friday morning were given an opportunity to visit Monticello, the home of Thomas Jefferson, near Charlottesville, and prior to the dinner on Friday evening, all interested were invited to inspect the Jefferson Searchlight on the roof of the Monticello Hotel. This is a 1,200,000,000-candle-power searchlight, using a direct current of 150 amperes, which is operated by the Virginia Public Service Company.

SATURDAY MORNING SESSION

At a session held in Madison Hall at 10:00 a. m. Saturday with J. A. Johnston, Member of the Executive Committee of the Virginia Section, A. S. M. E., presiding, the following program was presented:

Policies, Plans and Operations of the State Port Authority, by Mr. J. G. Bohannan, Petersburg, Va., Chairman of the Port Commissioners of Virginia, and Mayor of Petersburg.

The Virginia Public Service Company—Its Property—Organization—Aims, by Mr. A. W. Higgins, Charlottesville, Va., Vice-President and General Manager of the Virginia Public Service Company. Illustrated with large map of the system.

Obsolescence, by Mr. Gorton James, Washington, D. C., Chief of the Domestic Commerce Division of the Bureau of Foreign and Domestic Commerce.

At 1:00 p. m. on Saturday, a complimentary luncheon at the Commons was tendered by the university, and a considerable number of those in attendance at the meeting saw the Maryland Virginia football game held that afternoon. A section of the seats in the stadium was reserved for those who had previously registered requests for them.

Plans for the meeting were made under the supervision of a committee consisting of Professor W. S. Rodman, Chairman, and Mr. L. H. Williamson. The attendance at the sessions varied from 50 to 66, and all present considered the meeting most interesting and successful.

Future Section Meetings

Cleveland

Television, by J. W. Horton, Bell Telephone Laboratories. The meeting will be held in the Electric League Room of the Hotel Statler, at 8:00 p. m., December 15.

Today's Science, Tomorrow's Engineering, by L. A. Hawkins, General Electric Co. Electric League Room, Hotel Statler, 8:00 p. m., January 19.

Columbus

Power by Radio, by Phillip Thomas. Inspection of O. S. U. Broadcasting Station WEAO. January 6.

Illumination Meeting. January 27.

Erie

The Romantic Development and Economics of Niagara Power, by W. K. Bradbury, Niagara Falls Power Co. December 20.

Recent Developments in the Art of Communication, by S. P. Grace, Bell Telephone Laboratories. January 17.

Ithaca

Traffic in the Field of Radio Communication, by F. H. Kroger, Radio Corporation of America. January 26.

New York

Interconnection of Power Systems, by Alex Dow, President, Detroit Edison Co., and Farley Osgood, Consulting Engineer. January 13.

Pittsburgh

Engineers vs. Salesman—Who's Ahead?, by G. M. Gadsby, President, West Penn Power Co. December 13.

Symposium on A-C. Network Systems, by C. T. Sinclair, Byllesby Engg. & Management Corp., and H. R. Searing, United Electric Light and Power Co. Talk by Bancroft Gherardi, National President. January 10.

Pittsfield

The French Foreign Legion, by Major Pechkoff. December 6.

Hot Cathode Power Rectifiers, by A. W. Hull, General Elec. Co. December 20.

Floods and Flood Control, by Dr. Frank Bohn. January 10.

Developments in Steam Power Plants, by F. S. Collings. January 24.

St. Louis

Railroad Electrification, by J. V. B. Duer, Pennsylvania Railroad. December 21.

Important Small Materials Used in the Telephone Industry and Their Characteristics, by G. S. Rutherford, Western Elec. Co. January 18.

Sharon

New and Interesting Electrical Developments, by A. M. Dudley, Westinghouse Elec. & Mfg. Co. A talk will also be given by Larry Flint, writer and newspaper man. Banquet. December 6.

Raising the Submarine S-51, by Lieut.-Commander Edward Ellsberg, U. S. N. January 7.

Vancouver

Visit to Fire Dispatch Installation. January 10.

"Science Luncheon" of the American Institute

Cooperating with the National Research Council, Division of Engineering and Industrial Research, the American Institute of the City of New York will hold what it chooses to call a "Science Luncheon" Saturday, December 10th, at the Town Hall Club. The speakers will be Maurice Holland, Director of the Division of Engineering and Industrial Research, National Research Council, who will take for his subject, "The Vanishing American Genius," and L. A. Hawkins, executive engineer of the Research Laboratory, General Electric Company, Schenectady, N. Y., who will discourse on "Research—Organized Genius."

The American Institute at the close of the year will be 100 years old, and throughout this century it has directed its activities toward the encouragement and promotion of public welfare. A series of science demonstrations is being arranged under the able directorship of Doctor Harvey Brace Lemon of the University of Chicago. As a centenary activity of particular significance also is the publication of a book entitled "A Century of Industrial Progress" with an introduction to which Hon. Herbert Hoover has contributed. At this, the first luncheon, research and its relation to modern industry and activities will be evaluated, and the speakers are chosen for their first-hand knowledge of the current work in research laboratories.

Fiftieth Anniversary of Philadelphia Engineers Club

"Engineering Progress and World Civilization" will be the general subject for the Fiftieth Anniversary celebration of the Engineers Club of Philadelphia to open the evening of Friday, December 16, at 8:00 o'clock, when John R. Freeman, past-president of the American Society of Civil Engineers and Ambrose Swasey, past-president of the American Society of Mechanical Engineers will address the meeting on "The Past in Engineering Fifty Years ago—1877." This will be followed by an entertainment and smoker. A buffet supper will also be served.

Saturday morning will be given over to the ceremonies of honorary degrees to be conferred by the University of Pennsylvania upon several of the distinguished guests. A buffet luncheon will be served at noon, and the afternoon meeting on "The Present in Engineering—1927" will be addressed by William C. L. Eglin, President of The Franklin Institute, Howard Elliott, chairman of the Board, Northern-Pacific Railway Company and Charles M. Schwab, Honorary Member of the Engineers Club and president of the Iron & Steel Institute. For the evening meeting at 7:30 o'clock, the unique subject of "Future in Engineering—1977" will be discussed by Samuel Rea, Honorary President of the Engineers Club and Past President of the Pennsylvania Railroad, Dexter S. Kimball, President of the American Engineering Council and John Hays Hammond, past-president of the American Institute of Mining Engineers. All functions will be held at the Bellevue-Stratford with the exception of the convocation Saturady morning at College Hall. Ladies will be welcome; any non-members desiring to attend should communicate with the secretary, Mr. Charles E. Billin, Secretary, the Engineers Club of Philadelphia, 1317 Spruce Street, Philadelphia, Pa. prior to December 12.

Radio Engineers' 1928 Convention

The Third Annual Convention of The Institute of Radio Engineers is to be held on January 9th, 10th, and 11th, 1928. The program is to include the Annual Meeting of the Institute, reports of officers, installation of new officers, presentation of the Liebmann Memorial Prize to Dr. A. Hoyt Taylor of the United States Naval Institute, the series of technical sessions, inspection trips to a number of interesting places around New York and a dinner-dance on the evening of the 11th.

The general meetings and technical sessions will be held in the Engineering Societies Building, 33 West 39th Street, and the registration booth and convention headquarters will be in the lobby of the Engineering Societies Building.

Sixth Power Show

The Sixth National Exposition of Power and Mechanical Engineering will open December 6, 1927, when 180,000 square feet of Grand Central Palace New York will be utilized in the display of latest mechanical devices. The scope of the exhibit is not confined to the field of heat and power generation and utilization, but will include the allied field of ventilation and other modern problems of great importance. Refrigerating machinery will be represented by a group of fifty manufacturers; mechanical power transmission, welding, machine shop equipment and wood-working machinery will also hold conspicuous places in the exposition which will continue through December 10, simultaneously with the Annual Meetings of the American Society of Mechanical Engineers and the American Society of Refrigerating Engineers.

25th Annual Convention of American Road Builders' Association

Announcement has been made to the Chamber of Commerce of the American Road Builders' Association Convention January 9th to 13th, 1928, at Cleveland, Ohio. Special headquarters will be maintained at the Public Auditorium and at the Hollenden Hotel for visiting city officials, and they are invited to register and make use of headquarters during the Convention. Attendants will be in charge at all times, and William R. Hopkins, City Manager and Chairman of the City Officials' Committee, will gladly receive all inquiries of those interested. This will be the largest exposition of Road construction and road maintenance machinery and materials ever held including over 300 carloads of the latest machinery, equipment and materials. Papers will be presented of special interest to city officials who are urged to attend and take part in the discussion of various subjects presented by carefully selected authorities. There will be a "Pan-American Day" a portion of which will be given over to highway problems in North and South America, and in the evening, the delegates from Pan American countries will be the guests of the American Road Builders' Association at the Annual Banquet. Reservations should be made through Mr. A. J. Kennedy, Vice-Chairman, A. R. B. A. Hotel Committee Room 304, Chamber of Commerce Building, Cleveland, Ohio.

New Spanish Translation Available

The Spanish translation of the A. I. E. E. Standard for Electrical Measuring Instruments (No. 33) is now available. This standard applies to the following kind of indicating instruments: Ammeters, voltmeters, wattmeters, reactive volt-ampere meters, frequency meters, power-factor, reactive-factor and phase-angle meters and synchroscopes. It does not apply to curve drawing or contact making instruments nor to small instruments of types and sizes which are used where low cost is essential.

There are now 17 A. I. E. E. Standards translated into Spanish as follows: Nos. 1-5-7-8-9-10-11-13-14-15-16-19-22-30-33-37 and 41.

The work of translation has been done by a special committee of the Standards Committee, under the chairmanship of Dr. C. O. Mailloux. The Standards are published by the Bureau of Foreign and Domestic Commerce. Orders should be sent to the Superintendent of Documents, Government Printing Office, Washington, D. C. Prices of the pamphlets are as follows:

Nos. 5-7-8-9-10-11-13-16 and 22, ten cents.
Nos. 1-14-15-19-30-33-37 and 41, five cents.

Chicago Power Show

The exhibit at the 1928 Midwestern Engineering and Power Exposition Chicago, Feb. 14-17, 1928 will be a most forceful representation of progression to meet modern requirements demanded for the convenience of prosperity. It is expected that thousands will be in attendance to review the diversified and unique mechanisms there displayed.

Centennial of the Institution of Civil Engineers

The Institute has received a cordial invitation from the President and Council of the Institution of Civil Engineers of Great Britain, for members who may be in London early in June 1928 to attend an engineering conference to be held in connection with the celebration of the One Hundreth Anniversary of the issuance to that institution of a royal charter of incorporation. Further particulars of the subjects to be discussed will be available later. In the meantime, however, members of the Institute who are likely to be in London the first week in June 1928 are requested to send their names and addresses to Institute headquarters so that further plans may be communicated directly to them.

Provisions of Radio Treaty Being Completed

The International Radio-Telegraph Conference, after several plenary sessions, has nearly completed its task of formulating an international treaty covering the uses of radio. The work of the conference will probably be completed before the end of the month, according to the President of the Conference, Herbert Hoover.

Some of the articles of the convention already adapted and of interest to engineers are; the maintenance of stations "abreast of scientific and technical programs," and without interference; collection and coordination of information regarding radio services by the International Bureau of the Telegraphic Union at Berne, Switzerland; regulations covering operators, licensing, use of call waves, relays from land to mobile stations. Objection was raised to a provision requiring operators of experimental stations to be tested by their respective governments for their technical knowledge of radio.

The conference has been considering an invitation from the head of the Belgium delegation to fix the time of the International Radio Telegraph Conference to be held at Brussels in 1928 instead of 1930. There is considerable objection to the earlier date.

Doctor Coolidge Awarded Hughes Medal

Dr. W. D. Coolidge, assistant director of the research laboratory of the General Electric Company, has been awarded the Hughes medal by the Royal Society for "distinguished work on X-rays and the development of highly efficient apparatus for their production." The Hughes medal was first presented in 1913 to Dr. Alexander Graham Bell. Dr. Irving Langmuir, also of the General Electric research laboratory, received it in 1918.

ENGINEERING FOUNDATION

SPECIFIC INSTANCES OF ENGINEERING RESEARCH

Shortly after Ambrose Swasey suggested the creation of the Engineering Foundation in 1914, the World War broke out, and all eyes were turned to national security problems. In 1916 the newly-organized Engineering Foundation and the four Founder Societies joined with the National Academy of Sciences in establishing the National Research Council. Then, until 1923 the Engineering Foundation devoted the greater part of its resources to the support of the Research Council and the Council's division of engineering; but since then, it has returned to the intention for which it was created,—cooperation with the founder societies in projects affecting engineering at large, still retaining however, its connection with the Research Council.

Some of the national societies' projects in which the Foundation has cooperated include research on concrete and reinforced concrete arches; on steel columns for bridges and buildings; mining methods; properties of steam; bearing metals; lubrication; and strength of gear teeth. These are all subjects upon which research is obviously important and much needed. The projects in which the Foundation cooperated with the National Research Council were equally so. Some of these were research on the construction and maintenance of highways (Advisory Board on Highway Research); on welding (American

Bureau of Welding); injury to marine piling by the teredo and other small boring animals; molding sands for foundries (Committee on Molding Sands); pulverizing of ores, cements, and fuels (Pulverizing Committee); and on personnel research (Personnel Research Federation).

The mere enumeration and tabulation of work undertaken can lend but a vague idea of actual accomplishments, but the reports of the Foundation give information of its widespread activities.

As its funds grow and opportunity permits, Engineering Foundation hopes to assist in many significant researches for the benefit of the profession and the public at large.

P. B. McDonald

Engineers Predict Future of New York

On the evening of November 4 in the Engineering Auditorium the members of the New York Section of the A. I. E. E. heard six prominent engineers discuss the future of New York City. The first speaker, E. P. Goodrich, Consulting Engineer on City Planning for the Sage Foundation, had as his subject "Probable Growth of New York City and Distribution of Population," and devoted himself chiefly to the presentation of a large number of very interesting slides giving growth of population, industry, consumption of products and their inter-relation. The second speaker, R. H. Shreve, President of the New York Building Congress, described "Architectural Requirements and Building Service." He gave data relative to the factors limiting the size of buildings and mentioned as one of the developments which will possibly aid in the traffic and parking problems, the construction of buildings for office use with certain floors devoted to parking space for the machines of the occupants.

The next two speakers covered the transit situation. L. S. Miller, President of the New York, Westchester and Boston Railway Co. spoke on "Suburban Transportation," and C. E. Smith, St. Louis Consulting Engineer, who recently reported to Comptroller Berry on the solution of New York's transit problem, talked on "Urban Transportation." "Telephone Service" and the "Light and Power Service" were the last two topics and were covered respectively by J. L. Kilpatrick, Vice-President of the Western Electric Co. and John W. Lieb, Vice-President of the New York Edison Co. There was a total attendance of about 800.

Prize Awards for Safety Promotion

The American Road Builders Association is offering $1000 in prizes for the best ideas of possible usages for the promotion of safety in the streets and highways. More than 22,000 people were killed in the streets and highways of the United States during the first ten months of 1927, which emphasizes the necessity of further and immediate action in this regard, and this Road Builders association will welcome such suggestions and endorsements as those who may have pertinent ones to offer.

National Research Council

ACTIVITY IN INDUSTRIAL RESEARCH

As a result of his visit to Japan last fall at the time of the Third Pan-Pacific Science Congress, Maurice Holland, Associate of the Institute and Director of the Division of Engineering and Industrial Research of the National Research Council, prepared a brochure upon The Industrial Transition in Japan, which in cooperation with the Japan Society of New York, has just been published in attractive pocket size and given wide distribution among those interested in comparing the remarkable industrial progress of Japan during the last generation with the industrial status of other countries. Also in connection with industrial progress, an exhaustive bibliography of literature of the past several years relating to street and highway safety has been prepared by the Highway Research Board through its chairman, A. B. Fletcher, of the Bureau of Public Roads, and Doctor M. G. Lloyd, Chief of the Safety Section, Bureau of Standards has prepared and had printed a statement on the "Present Status of Legal Regulations of Automobile Headlights in the United States."

A meeting of the Committee on Electrical Insulation was held June 1927 at Detroit. Four papers had been prepared and published and three more were in course of preparation.

Volta Memorial Fellowship

A fund of $25,000, the income from which will be applied each year to post graduate work of an electrical engineer from Italy, in an American university, has been established by individuals, associations and corporations in this country who are interested in electrical development ,it has been announced by the Italy-America Society. The fund has been raised to mark the one hundredth anniversary of the death of Alessandro Volta, inaugurator of a new era in electricity.

It has been marked this year with a special program in connection with the International Exhibition at Lake Como, Italy, where announcement of the formation of the memorial fund in the United States was received with much enthusiasm. The student who will come to the United States will be selected competitively by the Associazione Elettrotecnia Italiana, which corresponds to the American Institute of Electrical Engineers. In the United States the administration of the fellowship is in the hands of the Italy-America Society.

Maurice A. Oudin, vice president of the International General Electric Company and chairman of the memorial committee, has outlined the purposes of the fellowship:

The committee in charge of establishing the memorial included: Thomas A. Edison, honorary chairman; Maurice A. Oudin, International General Electric Company, chairman; J. E. Aldred, Aldred and Company; Sosthenes Behn, International Telephone and Telegraph Company; Paul D. Cravath, Westinghouse Electric and Manufacturing Company; Gano Dunn, president, J. G. White Engineering Corp.; Giuseppe Faccioli, General Electric Company; General James G. Harbord, Radio Corporation of America; Thomas W. Lamont, ex-president of Italy America Society; John W. Lieb, New York Edison Company; Lloyal A. Osborne, Westinghouse Electric and Manufacturing Company; Philip Torchio, New York Edison Company; and Owen D. Young, General Electric Company.

Book Review

The New Reformation, by Michael Pupin. Charles Scribner's Sons, 271 pp., cloth, 5¾ x by 8¼, $2.50.

This book was published six weeks ago and it is already in its second edition. We cannot review it better than by quoting abstracts from opinions expressed:

From a letter of Ambrose Swasey:

A few days ago I secured a copy of your recent book "The New Reformation," and I only wish it were possible for me to express to you the pleasure it has given me . . . . With all my heart I thank you for this message . . . . and you can never know the great blessings these chapters will be to thousands of people today and for generations to come.

Cleveland, Ohio, Ambrose Swasey.
Nov. 1, 1927.

From a letter of Professor Jansky:

After reading your book "From Immigrant to Inventor" I was strongly impelled to write you expressing my appreciation of the book. I am now reading "The New Reformation" and can no longer inhibit the impulse to express as strongly as I can my enthusiasm of such a masterly piece of work. For some time I have had a hazy and indefinite notion that such a work ought to

Denver

The Range of Communication, by Bancroft Gherardi, National President, A. I. E. E. Illustrated with motion picture depicting the transoceanic telephone service. September 23. Attendance 90.

Romance of Power, by C. M. Ripley, General Electric Co. Illustrated. The meeting was preceded by a dinner. October 21. Attendance 200.

Transmission-Line Stability, by A. W. Copley, Westinghouse Elec. & Mfg. Co. Illustrated. October 28. Attendance 50.

Detroit-Ann Arbor

Recent Developments in Single-Phase Motors, by Prof. B. F. Bailey, University of Michigan. October 18. Attendance 275.

Erie

Taking the Teeth Out of Lightning, by H. M. Towne, General Electric Co. Illustrated. October 18. Attendance 80.

Fort Wayne

Electric Arc Welding in Manufacture and Construction, by D. H. Deyoe, General Electric Co. Illustrated. November 10. Attendance 110.

Indianapolis-Lafayette

The Trend of Science in Management, by L. W. Wallace, Executive Secretary, American Engineering Council. October 27. Attendance 427.

Kansas City

Aviation, by Capt. Francis Poindexter, Reserve Air Corps. Illustrated. October 17. Attendance 35.

Standardization in Engineering Work, by A. P. Denton, Denton Engg. & Construction Co., and

Liquid Air, Electricity and Magnetism, by Dr. H. P. Cady, University of Kansas. Joint meeting with University of Kansas Branch. November 1. Attendance 100.

Los Angeles

High-Voltage Oil Circuit Breakers for Transmission Networks, by Roy Wilkins, Pacific Gas and Electric Co. Illustrated. The meeting was preceded by a dinner. November 1. Attendance 135.

Lynn

Instruments Used in Aeronautics, by Prof. Wm. E. Brown, Mass. Inst. of Tech. Illustrated. October 26. Attendance 159.

Recent Developments in Electrical Insulation, by L. E. Barringer, General Electric Co. November 9. Attendance 125.

Pittsburgh

Tendencies in Modern Transportation, by N. W. Storer, Westinghouse Elec. & Mfg. Co. September 13. Attendance 400.

Television, by H. M. Stoller and J. W. Horton, The Bell Telephone Laboratories. October 11. Attendance 650.

Pittsfield

Inspection trip to the following industries: Cluett, Peabody and Co., Ford Motor Co., Ludlum Steel Co., and John A. Manning Paper Co. October 12. Attendance 150.

To the North Pole and Back Again, by Floyd Bennett, U. S. N. A dinner preceded the meeting. November 1. Attendance 900.

Portland

General Problems Relating to High-Voltage Systems, by R. D. Evans, Westinghouse Elec. & Mfg. Co. September 27. Attendance 70.

Providence

Modern Power-Plant Design in This Country and Abroad, by G. A. Orrok, Consulting Engineer. Illustrated. The talk was preceded by an inspection trip to the Somerset Station of the Montaup Electric Co. October 25. Attendance 80.

Rochester

Engineering Features of Radio Station WHAM, by A. B. Chamberlain, and

The General Subject of Broadcasting, by E. E. Chappell. After the talk the members visited the new WHAM Studio. Joint meeting with I. R. E. and R. E. S. October 7. Attendance 175.

St. Louis

The Emmet Mercury-Vapor Process, by L. A. Sheldon, General Elec. Co. Illustrated. September 21. Attendance 152.

The Economic Factors Affecting Apparatus Designs, by T. S. Perkins, Westinghouse Elec. & Mfg. Co. Illustrated. October 18. Attendance 51.

Schenectady

Smoker. October 21. Attendance 225.

Low Cost: What the Engineers Can Do, by W. R. Burrows, General Electric Co. Preceding the lecture a motion picture, entitled "The Making of Lamps," was shown. Joint meeting with A. S. M. E. October 27. Attendance 200.

Seattle

The Application of Carrier Current to Relay Protection, by A. S. Fitzgerald, General Electric Co. October 11. Attendance 77.

Sharon

The Modern Reproduction of Sound, by C. R. Hanna, Westinghouse Elec. & Mfg. Co. October 12. Attendance 158.

Spokane

General Problems Relating to High-Voltage Systems, by R. D. Evans, Westinghouse Elec. & Mfg. Co. October 3. Attendance 26.

A Carrier-Current Pilot System of Transmission-Line Protection, by A. S. Fitzgerald, General Electric Co. October 13. Attendance 20.

Springfield

Central-Office Machine Switching, by Ralph Sheppard, New England Telephone Co. October 17. Attendance 90.

Syracuse

Power-Transmission Systems and Interconnections, by Robert Treat, General Electric Co. Illustrated. October 31. Attendance 136.

Toledo

Research in Concrete Mixtures in Building Construction, by Col. Boyden. October 12. Attendance 71.

Toronto

Communication Interference, by J. L. Clark, Bell Telephone Co. October 14. Attendance 88.

Urbana

Theory and Manufacture of Electrical Measuring Instruments, by A. F. Corby, Weston Electrical Instrument Corp. Joint meeting with Electrical Engineering Society. October 18. Attendance 224.

Utah

Stability of High-Voltage Power-Transmission Systems, by A. W. Copley, Westinghouse Elec. & Mfg. Co. Illustrated. October 31. Attendance 30.

Vancouver

High Lights of Telephonic Transmission, by C. H. McLean, B. C. Telephone Co. Illustrated. November 1. Attendance 93.

Inspection trip to the Seymour-Douglas Exchange of the B. C. Telephone Co. November 5. Attendance 24.

A. I. E. E. Student Activities

ELECTRICAL SHOW AT PENNSYLVANIA STATE COLLEGE

In an electrical show held by the Pennsylvania State College Branch on Alumni Homecoming Day, October 29, 1927, the 22 exhibits covered a wide variety of subjects and were viewed by several thousand persons.

Some of the exhibits of an instructive nature included plans and pictures of a hydroelectric plant, a model substation and transmission line, Jenkins picture transmitting apparatus, automatic telephone equipment, electric meters and parts, a Tesla coil in operation, etc. Several exhibits illustrated use of colors in illumination.

Among the "trick" exhibits were a wireless light, a mysterious egg, rotating copper ball floating in a glass jar, a tin can lid motor, and a bucking motor.

There were several exhibits of household appliances and radio receivers. A Panatrope with loud-speakers in various parts of the room furnished music.

BRANCH MEETINGS

Alabama Polytechnic Institute

Automatic Control Systems, by W. P. Smith. A talk on "Electric Arc Welding" was also given. October 6. Attendance 63.

Smoker. October 27. Attendance 80.

University of Arkansas

Business Meeting. October 10. Attendance 15.

Types of Banks, by Mr. Collier, Vice-President, First National Bank of Fayetteville. October 20. Attendance 19.

Electric Heating Units, by Mr. Dorman, and

Testing Watthour Meters, by Mr. Beril. November 3. Attendance 13.

Armour Institute of Technology

Talk by E. S. Nethercut, Secretary, Western Society of Engineers on Dr. Pupin's book "From Immigrant to Inventor." Joint meeting with Armour Branch, W. S. E. October 21. Attendance 80.

Brooklyn Polytechnic Institute

Business Meeting. The following officers were elected: President J. Brown; Vice-President, H. Thieling; Treasurer, H. Steen; Secretary, F. Campbell. October 4. Attendance 53.

University of California

Business Meeting. October 12. Attendance 25.

Carnegie Institute of Technology

Experiences Abroad, by Prof. S. B. Ely;

The National A. I. E. E., by Prof. W. R. Work, and

The Branch of the A. I. E. E., by Prof. B. C. Dennison. October 5. Attendance 61.

Case School of Applied Science

The Work of the Branch Counselors, by Prof. H. B. Dates;

My Recent Trip to Europe, by Prof. T. D. Owens;

Experiences as a Student in Europe, by Prof. P. L. Hoover; and

Greatness of the Electrical Profession, by Mr. Mills. The meeting was preceded by a dinner. Mr. J. G. Currie, Chairman, outlined the program for the year. November 1. Attendance 35.

Catholic University of America

The Aims and Accomplishments of the A. I. E. E., by Prof. T. J. MacKavanaugh. The following officers were elected: President, J. V. O'Connor; Vice-President, B. A. Diggins; Secretary, R. H. Rose; Treasurer, D. V. O'Leary. October 18. Attendance 28.

Clemson College

Business Meeting. The following officers were elected: Chairman, A. P. Wylie; Secretary, W. J. Brogdon. October 29. Attendance 15.

Colorado Agricultural College

Generation and Distribution of Power, by Clarence Boyd. October 24. Attendance 13.

University of Colorado

The Romance of Power, by C. M. Ripley, General Electric Co. Illustrated. October 19. Attendance 500.

Nineteenth Annual Applefest. A talk was given by Dean Milo S. Ketchum, University of Illinois. The meeting was concluded by entertainment and refreshments. November 2. Attendance 500.

University of Denver

Business Meeting. October 12. Attendance 10.

Modern Telegraphic Methods and Equipment of the Western Union Telegraph Company, by Glen W. Earnhart. October 21. Attendance 30.

Duke University

The A. I. E. E., by Prof. S. R. Schealer. October 17. Attendance 13.

Georgia School of Technology

Aims of the Branch and of the A. I. E. E., by Prof. E. S. Hannaford. October 14. Attendance 72.

Three Wire Railway System, by C. E. Bennett, Georgia Power Co. The following officers were elected: Chairman, J. A. Hart; Vice-Chairman, F. W. Bush; Secretary-Treasurer, O. P. Cleaver. October 28. Attendance 70.

University of Idaho

The Machine Age, by C. W. Miller, student, and

A More Flexible Lighting System, by R. P. Morris. November 1. Attendance 21.

Iowa State College

Business Meeting. October 25. Attendance 11.

State University of Iowa

Comparison of Series and Multiple Street Lighting Systems, by W. E. Christiansen;

Insulation Resistance in Electrical Machinery, by H. W. Franks; and

Relation of Steam to Hydroelectric Generation, by L. L. Heskett. October 12. Attendance 27.

Measurement of Power by the Oscillograph, by G. R. Parizek, and

Changing Transformer Voltage, by W. H. Wickham. October 19. Attendance 23.

The Place of the Synchronous Motor in Industry, by W. W. Wertzbaugher, and

Some Theories of Lightning, and Lightning Protection of Oil Reservoirs, by Alfred Feldt. October 26. Attendance 26.

The Operation and Care of Storage Batteries, by R. N. Weldy;

Automatic Switching Control for Mercury Arc Rectifiers, by E. L. Anderson;

Some Interesting Factors of Fuses, by H. W. Johnston; and

The History of Mathematics, by J. T. Hicklin. November 9. Attendance 29.

University of Florida

Talks were given by W. H. Johnson and R. E. Lee, students, on their work during the summer with the Westinghouse Elec. & Mfg. Co. and General Electric Co., respectively. October 10. Attendance 24.

Lehigh University

Some Developments in the Communication Field, by H. S. Sheppard, A. T. & T. Co. November 10. Attendance 100.

Lewis Institute

Business Meeting. October 11. Attendance 60.

Human Engineering, by Alex D. Bailey, Commonwealth Edison Co. Joint meeting with W. S. E. November 2. Attendance 125.

Louisiana State University

Business Meeting. October 28. Attendance 20.

University of Maine

Machine Switching, by J. M. Bridges, student. October 19. Attendance 17.

Marquette University

Elimination of Defective Equipment in the Central Office, by George Baumbach, Wisconsin Telephone Co. Mr. J. R. Adriansen reported on the Detroit Convention and Prof. J. F. H. Douglas outlined the advantages of attending the Great Lakes District Convention in Chicago. October 6. Attendance 25.

Massachusetts Institute of Technology

What Kind of an Engineering Job Can I Get and How Do I Go About Getting It, by W. O. Bursch, General Electric Co. The talk was preceded by a film showing some of the tests made by the members of the General Electric Cooperative and Graduate Courses for Students. Free supper. October 28. Attendance 305.

Michigan State College

A film of the Steam and Hydroelectric Plants of the Consumers Power Corporation was shown. November 1. Attendance 53.

Inspection trip to the Moore's Park Light and Power Plant of Lansing. November 2. Attendance 29.

School of Engineering of Milwaukee

Transmission and Distribution Systems, by G. G. Post, The Milwaukee Electric Railway and Light Co. Illustrated. October 14. Attendance 175.

University of Minnesota

Smoker. The following committees were appointed: Publicity, A. I. E. E. Board of Control, Membership and Meetings and Papers. M. E. Fiene, Teaching Fellow, and Mr. Schweppe, graduate student, told of their experiences with the General Electric Co. and Westinghouse Elec. & Mfg. Co., respectively, during the past summer. October 4. Attendance 50.

Chicago District Electrical Developments, by B. G. Jamieson, Commonwealth Edison Co. A dinner preceded the meeting. October 24. Attendance 80.

University of Missouri

Summer Experience with the Panhandle Power & Light Co., Borger, Texas, by C. V. Dunn, student;

Summer Experience with Westinghouse Service Station, Chicago, Ill., and with American Sheet and Tin Plate Co., Gary, Ind., by Lionel Schott, student; and

Summer Experience with the American Telephone & Telegraph Co., St. Louis, Mo., by C. E. Schooley, student. October 12. Attendance 35.

Types of Electric Welding, by R. Muench, student, and

Summer Experience with Westinghouse Electric & Manufacturing Company, by E. S. Rehagen, student. November 9. Attendance 33.

Montana State College

Plastic Flow and the Strength of Cold-Worked Steel, by E. B. Norris, Dean of Engineering. October 13. Attendance 180

Power Developments and Generation, by E. A. Elge. October 27. Attendance 124.

Banquet. November 9. Attendance 72.

University of Nebraska

My Trip Around the World, by Carl Madsen, Westinghouse Elec. & Mfg. Co. October 13. Attendance 68.

University of Nevada

Power Transmission, by P. B. Garrett, Westinghouse Elec. & Mfg. Co. The lecture was preceded by a moving picture entitled "Electrically Made Steel." September 21. Attendance 47.

Motion pictures, entitled "Bituminous Coal" and "Anthracite Coal," were shown, in connection with which Prof. O. J. Mithoug gave a talk. October 20. Attendance 33.

Newark College of Engineering

Earth Inductor Compass, by Mr. Speckman, student, and

Phantasmal Visions, by Mr. Condit, student. October 19. Attendance 19.

University of New Hampshire

Thompson Integrating Wattmeter, by E. A. Goodwin, and

Collection of Current from Overhead Contact Wires, by E. F. Lafond. October 12. Attendance 39.

Business Letter Writing, by R. M. Fulsom, and

Wiring Requirements of the Portsmouth Power Co., by H. W. Lawry. October 19. Attendance 39.

The Contract of the Portsmouth Power Company and the University of New Hampshire, by J. M. Lee and Leon Morrissette, and

How to Get the Job You Want, by L. L. Landon. October 26. Attendance 35.

Oscillography, by Charles Morrels and A. R. Neal, and

Incandescent Lamps, by M. B. Sargent. November 2. Attendance 35.

Lightning, by L. C. Simpson and J. Q. Wendell, and

A. C. Wattmeters, by J. F. Stevens. November 9. Attendance 33.

College of the City of New York

Trip to the Museum of Peaceful Arts. October 25. Attendance 15.

Extension of New York City, by T. K. Thompson. Illustrated. Joint meeting with A. S. C. E. November 3. Attendance 58.

Motion pictures, entitled "Laying the World's Fastest-Cable" and "Transoceanic Radio," were shown. Joint meeting with C. C. N. Y. Radio Club. November 10. Attendance 33.

New York University

Business Meeting. Program Committee was appointed and it was decided that the Branch meeting should be held on the second Thursday of each month. October 6. Attendance 30.

Industrial Motor Control, by H. L. Perdue, General Electric Co. Illustrated. October 13. Attendance 36.

Radio Circuits, by Alexander Senauke, Popular Science Institute. November 3. Attendance 34.

Typical Water-Power Developments of East and West Coasts, by R. P. Crippen, Carolina Power and Light Co. October 18. Attendance 96.

University of North Carolina

Amateur Radio, by George Rose, student. October 20. Attendance 39.

Use of Protective Relays, by C. C. Hazell, student, and

Holes, Poles, and Guys, by J. D. McConnell, student. November 3. Attendance 27.

University of North Dakota

Business Meeting. The following committee chairmen were appointed: Program, Norman Cross; Membership, Robert Sturtevant. October 3. Attendance 11.

The A. I. E. E., by Prof. D. R. Jenkins;

Experiences with the Curtiss Light Company During the Summer Months, by Harry Olson; and

Summer Experiences with the Westinghouse Elec. & Mfg. Company, by Nels Anderson. A motion picture on the "100-Kw. Vacuum Tube" was shown. October 17. Attendance 11.

Inspection trip through the East Grand Forks Plant of the American Beet Sugar Company. Joint trip with A. S. M. E. October 21.

A Method of Regulating the Thickness of Rubber and Paper Sheets, by Torval Kittleson; and

Progress in the Electrification of Railroads, by Alfred Botten. A motion picture on "Diesel-Electric Drive for Ships" was presented by Robert Sturtevant. October 27. Attendance 16.

Electricity in the Copper Mines, by John Walsh, and

Radio Broadcasting Apparatus, by Norman Cross. Motion picture on the Synchronous Condenser was shown. November 7. Attendance 16.

Ohio University

Business Meeting. The following officers were elected: Chairman, C. C. Kelch; Vice-Chairman, A. H. Nyles; Secretary-Treasurer, H. W. Giesecke. October 23.

Ohio Northern University

The Purposes of the A. I. E. E., by Professor I. S. Campbell. September 15. Attendance 35.

Electric Welding, by R. Lebengood, and

Automatic Substations, by J. L. Simmons, President. September 29. Attendance 27.

What is Engineering?, by Emerson Smith. November 3. Attendance 28.

Oklahoma Agricultural and Mechanical College

Uses of Power Transformers, by Charles Wyatt. Motion pictures, entitled "Power Transformers" and "Busy Body," were shown. October 19. Attendance 90.

Oregon State College

Student Enrolment in the A. I. E. E., by Prof. F. O. McMillan. Chairman J. D. Hertz read the By-laws concerning presentation of papers and urged that all students prepare papers. October 13. Attendance 72.

Smoker. Prof. R. H. Dearborn spoke on the "Activities of the Branch." A talk was also given by Prof. F. O. McMillan on "The Importance of Student Membership and Activity in A. I. E. E. Affairs, Especially the Preparation and Discussion of Papers As a Means of Developing Engineering Ability." Entertainment and refreshments. November 2. Attendance 80.

Pennsylvania State College

After Graduation—What?, by Prof. C. L. Kinsloe. October 26. Attendance 87.

University of Pittsburgh

Business Meeting. The following officers were elected: Chairman, K. A. Wing; Vice-Chairman, R. P. Snyder; Secretary-Treasurer, R. H. Perry. September 30. Attendance 45.

Wire, by R. P. Snyder;

Is Flying Really Safe?, by R. H. Perry; and

Bees, by K. A. Wing. October 7. Attendance 43.

Design of Indoor Bus Supports, by R. H. Albright, and

Tendencies in Design of Modern Street Railways, by H. E. Zankey. October 14. Attendance 43.

An Outing, by G. C. Bohn, and

The Latest in Electric Locomotive Design, by W. H. Wamhoff. October 21. Attendance 38.

Electric Switch Lamps, by C. Caveny. October 28. Attendance 43.

Princeton University

Business Meeting. The following officers were elected: Chairman, R. H. MacGregor, Jr.; Secretary, W. Wilson. October 17. Attendance 7.

Purdue University

Distribution Practises on 11,000-Volt, Bare Copper Wire Lines of Texas Power & Light Co., by S. F. Welch. Illustrated. October 18. Attendance 60.

Engineering Patents, by Prof. L. D. Rowell. Illustrated. November 8. Attendance 40.

Rensselaer Polytechnic Institute

Talks were given by the following students on their work during the Summer with various public utilities: S. Benson—United Electric Light Co.; H. Pratt, General Signal Co.; M. Reeks and O. Smith, New York Edison Co.; R. Knapp, American Tel. & Tel. Co.; W. Mayott, Hartford Electric Light Co. October 10. Attendance 73.

Rhode Island State College

Electronic Rectifiers, by J. H. Allenson. October 14. Attendance 28.

A Review of the History, Development and Uses of the Coolidge Vacuum Tube, by F. M. Hammett, student. October 21. Attendance 32.

Motion picture on "The Manufacture of Porcelain Insulators" was shown. November 4. Attendance 41.

Rutgers University

Storage Batteries, by H. W. Willhardt, student, and

The Steam Generating Plant at Hollywood, by H. W. Dettmer, student. October 10. Attendance 16.

South Dakota State School of Mines

Business Meeting. Mr. R. Mytinger was elected Secretary. September 27. Attendance 19.

Talks were given by the following students on their work during the Summer with various companies: E. Perrenoud, N. W. Bell Telephone Co.; O. Taylor, North Western States Portland Cement Co.; R. Osborn, C. B. & Q. Machine Shops at Edgemont, S. D. November 1. Attendance 22.

Operation of D. C. Generators and Motors at Speeds and Voltages Other Than Those Specified on the Name Plate, by Mr. Schell. October 19. Attendance 12.

University of Southern California

Business Meeting. The following officers were elected: Chairman, Lester Bateman; Vice-Chairman, A. E. Sayler; Treasurer, Zoeth Cummings; Secretary, L. F. Slezak. October 5. Attendance 20.

Installation of Electric Railways in the Copper Mines of Northern Chile, by H. A. McCarter, Westinghouse Elec. & Mfg. Co. Illustrated. October 12. Attendance 43.

Inspection trip to the Oil Refinery of the Standard Oil Company at El Segundo. October 21. Attendance 45.

Stanford University

Talks were given by N. R. Morgan and R. W. Clark, students, on their Summer Work. October 18. Attendance 32.

Stevens Institute of Technology

Business Meeting. The following officers were elected: Chairman, W. N. Goodridge; Secretary-Treasurer, S. J. Tracy. October 27.

Swarthmore College

Mining Engineering as a Profession;

Rubber Research Laboratory of the Bureau of Standards, and

Machine Shop Practise. October 13. Attendance 50.

University of Tennessee

Inspection trip to the WNOX Broadcasting Station of the Peoples Telephone Co. November 2. Attendance 25.

Texas A. & M. College

Solenoids and Toroids, by S. H. Simpson;

Television, by W. C. Tinus; and

Diesel-Electric Ferries, by W. C. Dickinson. October 14. Attendance 75.

University of Texas

Prof. J. M. Bryant explained the activities and work of the A. I. E. E. and discussed some of the latest methods used in the manufacture of electrical machinery. October 5. Attendance 14.

Power Line Up-Keep, by J. B. Robuck, student. October 26. Attendance 11.

University of Utah

Business Meeting. D. K. Brake was elected Vice-Chairman to succeed C. E. White, present Chairman. October 18. Attendance 21.

Virginia Military Institute

What a College Graduate in Electrical Engineering Is Equipped To Do, by Capt. J. S. Jamison; *The Engineering Problems of the Reconstruction of the Rheims Cathedral*, by Cadet G. W. Day; *Electrolytic Production of Zinc*, by Cadet E. F. James; and

The Completion of the Moving Picture Booth and Installation of the Motor Generator Set at V. M. I., by Cadet D. N. Higgins. October 29. Attendance 24.

State College of Washington

Prospects for the Future, by Dean H. V. Carpenter. October 5. Attendance 41.

University of Washington

The Columbia Basin Project, by W. T. Batcheller. October 14. Attendance 33.

Relay Operation and Maintenance, by G. R. Rice, Puget Sound Pr. & Lt. Co. November 4. Attendance 23.

The Induction Lamp, by W. T. Kelley, student, and

The Chelan Power Project, by H. H. Smith, student. October 28. Attendance 21.

Washington University

Automatic Substations, by Joseph Mazanec, Jr., Secretary. October 20. Attendance 28.

Synchronous Motors, by S. H. Mortenson, Allis-Chalmers Mfg. Co. November 8. Attendance 41.

Washington and Lee University

Business and Social Meeting. October 21. Attendance 35.

West Virginia University

Keeping Pump Primed Without Foot Valve, by A. L. Lindlay; *Dismounting the Top Cord of a Bridge*, by S. C. Hill; *One-millionth of an Inch Photograph*, by L. T. Kight; *Incandescent Lighting*, by C. M. Borror; *Sub-station Design*, by F. M. Farray; *Large Hydroelectric Plant at Equzon, France*, by H. H. Hunter; *Squaring a Circle*, by D. Carle; and *The Flivver Passes*, by R. O. Fletcher. October 3. Attendance 35.

New Alloy of Copper, by G. B. Pyles; *Heroes of the Underground*, by E. W. Conway; *What's Wrong with Science?*, by C. C. Coulter; *Cement*, by F. D. McGinnis; *Sound Compass*, by W. S. Bosely and R. H. Pell; *Process of Manufacturing and Testing Choke Coils for Radio Power*, by M. S. Diaz; *Demand for Power*, by A. H. Huggins; *Electro-Deposition of Rubber Now Possible*, by Earl Milam; and *Comparison of Street Light Control Methods*, by W. T. Myers. October 10. Attendance 34.

Wiring Houses for Radio, by J. E. Cooke; *Baseball at Night*, by D. E. Akins; *Principle of Television*, by T. R. Cooper; *Service and Repair Records for Electric Motors*, by J. W. Schramm; *Benjamin Garver Lamme*, by F. H. Backus; *What the Gas Car Means to the Railroad*, by G. E. Phillips; *High Pressure Steam; Its Advantages and Disadvantages*, by R. N. Kirchner; *Safety and the Engineer*, by S. J. Donley; *Service in the Electric Industry*, by H. H. Brosuis; and *Electrification of the Virginian Railway*, by C. Clark. October 17. Attendance 32.

Electricity Speeds Up Crops, by G. I. Birner; *Protection of Reservoirs from Lightning*, by Ivan Vannoy; *Concrete Butts Prolong Life of Wooden Poles*, by A. L. Lindlay; *Erecting a Substation*, by L. T. Kight; *The Breathing Action of Electrical Equipment*, by John Tinivell; *What is Electricity?*, by M. S. Diaz; *Work of the Bureau of Mines and Its Methods*, by C. L. Parks; *Pacific Fliers Led by Radio Beacon*, by F. M. Farray; and *Building of Concrete Roads*, by H. H. Hunter. October 24. Attendance 30.

Is Flying Safe?, by G. B. Pyles; *Incandescent Lighting*, by C. M. Borror; *Faster Motor Boats*, by E. W. Conway; *Measuring Astronomical Distances*, by F. D. McGinnis; *Locating*

Mineral Beds by Radio, by C. C. Coulter; *A Precision Measurement of Puncture Voltage*, by R. O. Pletcher; *Long Distance Transmission*, by M. C. Clark; *The Use of Heat Generated by Electricity*, by A. H. Huggins; and *The Process of Power Installation*, by D. Carle. October 31. Attendance 32.

Evolution of the Hollow Conductor, by T. R. Cooper; *Electrification of North America*, by F. H. Backus; *Ventilation of the Holland Tunnel*, by J. W. Schramm and W. T. Myers; *Protection of Supervisory Control Systems from Lightning and Magnetic Induction*, by G. E. Phillips; and *Colossal Ad. Lights, Times Square, New York*, by W. S. Bosely. November 7. Attendance 33.

University of Wisconsin

Aims of the A. I. E. E., by Prof. C. M. Jansky. October 19. Attendance 50.

Worcester Polytechnic Institute

The Mohammedan Lands, by Prof. H. B. Smith. Illustrated. May 17. Attendance 30.

University of Wyoming

Business Meeting. Program and Membership Committees were appointed. October 25. Attendance 7.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is adminstered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m

BOOK NOTICES, OCT. 1-31, 1927

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ALTERNATING-CURRENT MACHINERY.

By Richard E. Brown. N. Y., John Wiley & Sons, 1927. 274 pp., illus., diagrs., 9 x 6 in., cloth. $3.00.

A text-book planned to give a thorough treatment of the principles of a-c. machinery, especially for students already familiar with the principles of a-c. circuits. Emphasis is placed on the analysis of the performance of the machines. Numerous problems are provided for solution with the text or in the machinery laboratory. The book reproduces the course given by its author at the University of Pennsylvania.

WEHR-UND STAUANLAGEN.

By Paul Böss. Ber. u. Lpz., Walter de Gruyter & Co., 1927. 132 pp., illus., diagrs., 6 x 4 in., cloth. 1,50 r. m.

Intended to give the student a brief survey of the various possibilities for storing water and of the principal points to be considered in planning and building storage works. The different types of dams are described, and the static and hydraulic equations necessary for designing them are given.

WARMETECHNISCHE BERECHNUNG DER FEUERUNGS-UND DAMPFKESSEL-ANLAGEN.

By Friedrich Nüber. 4th edition. Mün. u. Ber., R. Oldenbourg, 1927. 116 pp., diagrs., tables, 7 x 4 in., cloth. 4,20 r. m.

Brings together in a book of convenient size for the pocket, the principles, formulas, experimental data and other information required by designers and operators of industrial heating plants and boiler plants. The book is not a text for students, but a convenient practical reference work for the engineer. Four editions have appeared in eight years.

THEORY OF THERMIONIC VACUUM TUBE CIRCUITS.

By Leo James Peters. N. Y., McGraw-Hill Book Co., 1927. 256 pp., diagrs., tables, 9 x 6 in., cloth. $3.00.

The aim of the author is to develop conventions and methods which may be used to treat electrical networks and systems containing trielectrode devices. He endeavors, by the study of selected circuits and topics, to illustrate and fix in the mind of the reader the methods and conventions used in arriving at the performance of triode circuits, and thus to give him a knowledge of fundamental theory and a familiarity with methods which will enable him to investigate other systems and circuit arrangements than those discussed in the book.

SPECTROSCOPY, v. 3.

By E. C. C. Baly. 3rd edition. N. Y., Longmans, Green & Co., 1927. 532 pp., illus., diagrs., tables, 9 x 6 in., cloth. $7.50.

The third volume of this treatise discusses those developments in spectroscopy which are the more immediate results of the Bohr theory. The spectral series, the Teeman and Stark effects, and emission band spectra are treated with considerable fullness, much experimental work being described and the principal advances in atomic theory discussed as well.

SIEMENS JAHRBUCH, 1927.

By Siemens & Halske u. Siemens-Schuckertwerke. Berlin, V. D. I. Verlag, 1927. 472 pp., illus., port., diagrs., 8 x 6 in., cloth. Price not quoted.

The first issue of a series in which the Siemens & Halske and the Siemens-Schuckert companies intend to collect each year the results of their research and progress which appear of permanent worth. The articles cover a wide range and are well illustrated. The series will be a decided help to the student of electrical history as well as a convenient summary of development in our understanding and utilization of electricity.

SCIENTIFIC MARKETING MANAGEMENT.

By Percival White. N. Y., Harper & Bros., 1927. 318 pp., graphs, charts, 9 x 6 in., cloth. $4.00.

The aim of this book is to present the principles and general procedure of scientific marketing, so far as they have been developed, and to illustrate their application to specific cases. The book should assist those who wish to build a system of marketing for an individual company.

PRINCIPLES AND PACTICE OF MINE VENTILATION.

By David Penman and J. S. Penman. Lond., Charles Griffin & Co.; Phila., J. B. Lippincott Co., 1927. 303 pp., illus., diagrs., 9 x 6 in., cloth. $10.00.

Written to meet the English requirements for Colliery Manager's Certificates of Competency, this work covers mine ventilation and topics connected with it, such as explosions, safety lamps, spontaneous combustion and underground fires, and rescue and recovery work. It is intended for use as a text-book and also for reference.

POCKET-BOOK OF MARINE ENGINEERING RULES AND TABLES.

By A. E. Seaton and H. M. Rounthwaite. 17th edition. Lond., Charles Griffin & Co., 1927. 770 pp., diagrs., tables, 6 x 4 in., fabrikoid. 8s 6d.

Since the last edition of this well-known pocket-book, some changes in procedure and practise in marine engineering have taken place. These have been noticed in this edition, and the text has been brought up to date.

PHYSICS FOR COLLEGES.

By H. Horton Sheldon, C. V. Kent, Carl W. Miller and Robert F. Paton. N. Y., D. Van Nostrand Co., [1927]. 655 pp., illus., 9 x 6 in., cloth. $3.75.

A general text, the work of four experienced teachers, each of whom has prepared a section of the book. The text is readable and classical and modern concepts are interwoven throughout. The book has been tested by class-room use before publication.

MODERN WATER WORKS PRACTICE.

By F. Johnstone Taylor. Lond., Ernest Benn, 1927. 272 pp., illus., tables, 8 x 5 in., cloth. 18s.

A treatise covering the essential features of water works of moderate size. Modern methods of construction are discussed as well as modern methods of pumping and purification.

MODERN ELECTRICAL ILLUMINATION.

By Cyril Sylvester and Thomas E. Ritchie. Lond. & N. Y., Longmans, Green & Co., 1927. 416 pp., illus., tables, 10 x 7 in., cloth. $15.00.

After explaining the principles of illumination and vision, the book discusses the lighting of shops, stores, streets, public buildings, theaters, dwellings, trains, etc. Chapters are devoted to floodlighting, stage lighting, train lighting, and to miscellaneous subjects. The book covers the subject in detail and contains many excellent photographs showing current English practise.

MEHRSTIELIGE RAHMEN.

By A. Kleinlogel. 2nd edition. Berlin, Wilhelm Ernst & Sohn, 1927. 448 pp., 9 x 7 in., paper. 28,-r. m.

A large collection of formulas for the solution of statically indeterminate structures, prepared for the use of structural engineers. The formulas cover all the systems that ordinarily are met with in practise, and in each case a complete solution is provided. The work will be of great assistance to designers, by shortening computations.

MECHANICS OF MACHINERY.

By C. W. Ham and E. J. Crane. N. Y., McGraw-Hill Book Co., 1927. 504 pp., illus., diagrs., tables, 9 x 6 in., cloth. $4.00.

This textbook combines in a single volume courses of instruction in mechanism and in the kinematics and dynamics of machinery, the aim being to present enough material to give the student a working knowledge of both these subjects in the time ordinarily available in a curriculum. In the first section the fundamental mechanisms and the theory of their operation are explained. In the second section the student is taught to analyze the forces and the motions in these mechanisms or machines.

MACHINE DESIGN DRAWING ROOM PROBLEMS.

By C. D. Albert. 2nd edition. N. Y., John Wiley & Sons, 1927, 355 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.50.

A complete drawing-room course in general machine design, based upon the author's experience at Cornell University. A knowledge of kinematics, mechanics, and engineering drawing is presupposed.

This edition has been revised and enlarged. The tables have been brought up to date, and certain sections have been rewritten.

DIE LEHRE VOM TROCKNEN IN GRAPHISCHER DARSTELLUNG.

By Karl Reyscher. 2nd edition. Berlin, Julius Springer, 1927. 74 pp., diagrs., tables, 9 x 6 in., paper. 4,50 r. m.

Discusses the steps in drying processes on the basis of the Müller heat diagram. Diagrams are given for air saturated with moisture and for the material undergoing drying, and their use to promote economy in drying practise is illustrated.

INTERNATIONAL CRITICAL TABLES OF NUMERICAL DATA, PHYSICS, CHEMISTRY AND TECHNOLOGY. v. 2.

By National Research Council. N. Y., McGraw-Hill Book Co., 1927. 616 pp., diagrs., tables, 11 x 9 in., cloth. Sold only on subscription for set of 5 vols., $60.00, payable at rate of $12.00 per vol., as issued.

This volume contains the most accurate data available upon the properties of a variety of natural and industrial materials and products. Woods, building stones, ceramic materials, fuels, lubricants, oils and waxes, rubber, leather, insulating materials, and metals are among the more important materials included. The volume will be indispensable in manufacturing plants, laboratories, and engineering offices.

HYDROCHLORIC ACID AND SODIUM SULFATE.

By N. A. Laury. N. Y., Chemical Catalog Co., 1927. (Amer. Chem. Soc. Monograph Series). 127 pp., illus., tables, 9 x 6 in., cloth. $4.00.

This monograph presents the information commonly wanted in convenient form. The properties of the acid and of sodium sulfate, the principal raw materials and the finished products, furnaces, methods of manufacture and economic factors are discussed from the viewpoint of the engineer and the manufacturer.

HISTORY AND DEVELOPMENT OF ROAD TRANSPORT.

By James Paterson. Lond. & N. Y., Isaac Pitman & Sons, 1927. (Pitman's Transport Library). 118 pp., illus., 9 x 6 in., cloth. $1.75.

Describes how roads develop, especially those in England, the evolution of the wheeled vehicle, the locomotive and the motor car, road transport during the last century, and the effects of the motor car upon transport. A convenient brief survey of a large subject.

HISTORIC RAILROADS.

By Rupert Sargent Holland. Phila., Macrae Smith Co., 1927. 343 pp., illus., 9 x 7 in., cloth. $4.00.

A popular account of the origin of the locomotive and of the development of railroads in various lands. Some of the more important railroads in each continent are described. While the books adds nothing new to history, it supplies a readable survey of a wide field.

FLAME AND COMBUSTION IN GASES.

By William A. Bone and Donald T. A. Townend. Lond. & N. Y., Longmans, Green & Co., 1927. 548 pp., illus., plates, diagrs., tables, 10 x 6 in., cloth. $12.00.

A review of the principal researches from the time of Robert Boyle to the present day, with special attention to those of the modern period inaugurated in 1880. The book opens with a historical review of the period 1660 to 1880. Succeeding sections survey systematically the present state of science concerning the Initiation of Flame and Detonation in Gaseous Explosions, Explosions in Closed Vessels, the Mechanism of Gaseous Combustion, and Catalytic Combustion. Each section has a bibliography.

The chemical aspects of the subject are emphasized, but this extensive exposition of the underlying principles of gaseous combustion will also be of interest to engineers and physicists.

ENGINEERING PROBLEMS MANUAL.

By Forest C. Dana and Elmer H. Willmarth. N. Y., McGraw-Hill Book Co., 1927. 187 pp., diagrs., tables, 8 x 5 in., fabrikoid. $2.00.

A number of engineering schools give special courses to beginning students, which are planned to develop good habits of work and study. These courses, commonly known as "Engineering Problems," are based upon practical engineering situations and call for a coordination of mathematics and physics in an engineering atmosphere.

The present work is prepared for the courses given at Iowa State College and is to be used as a notebook for reference when solving problems, in connection with class discussions. It contains specifications for well-organized computation sheets, notes on basic engineering principles and their use, methods of computation, problems, and a collection of tables.

ELEMENTS OF TELEPHONE TRANSMISSION.

By H. H. Harrison. N. Y., Longmans, Green & Co., 1927. 147 pp., diagrs., tables, 8 x 5 in., cloth. $2.00.

A brief introduction for the elementary student. Intended to give him a grasp of the physical processes that occur in long circuits, and to enable him to understand the more advanced texts.

ELEKTRIZITAT IN DER LANDWIRTSCHAFT.

By C. Buschkiel. Ber. u. Lpz., Walter de Gruyter & Co., 1927. (Siemens-Handbücher, bd. 12). 171 pp., illus., tables, 8 x 6 in., cloth. 4,50 r. m.

An interesting semi-technical description of the possible uses of electricity on the farm. The ways in which electricity can be used for power, illumination, and heating are explained, directions for selecting and installing proper equipment are given, and economic question are discussed. A section is devoted to signals, telephones, radio receivers, clocks, etc. The book is profusely illustrated and attractively printed.

DICTIONARY OF APPLIED CHEMISTRY, v. 7.

By Sir Edward Thorpe. Revised and enlarged edition. Lond. & N. Y., Longmans, Green & Co., 1927. 765 pp., illus., 9 x 6 in., cloth. $20.00.

With this volume the new edition of this valuable reference work is completed. Long an essential part of every chemical library, the revision maintains former standards and will be welcomed by all who have need for accurate information on the applications of chemistry.

AMERICAN SHIP TYPES.

By A. C. Hardy. N. Y., D. Van Nostrand Co., 1927. 262 pp., illus., diagrs., 9 x 6 in., cloth. $5.00.

There has developed in the United States, says this author, an important mercantile marine which is entirely domestic and which differs in its characteristics materially from local or domestic shipping in other parts of the world. In this volume he describes the varieties of cargo and passenger vessels, ferry-boats, towboats, dredges and other vessels that have been developed to meet requirements along our coasts, on the Great Lakes, and on our inland waterways. The characteristics of each type and the interrelations of these types are shown, and probable developments are discussed.

DIE BEKAMPFUNG DES ERD-UND KURZSCHLUSSES IN HOCHSTSPANNUNGSNETZEN.

By Paul Bernett. Mün. u. Ber., R. Oldenbourg, 1927. 48 pp., diagrs., tables, 10 x 7 in., paper. 4.-r. m.

Discusses the author's experience with methods of protecting transmission lines from grounding and short-circuiting, and also current methods for locating faults in overhead lines.

BERECHNUNG VON DREHSTROM-KRAFTUBERTRAGUNGEN.

By Oswald Burger. Berlin, Julius Springer, 1927. 116 pp., diagrs., tables, 9 x 6 in., paper. 7,50 r. m.

This book, by the Chief Engineer of the Siemens-Schuckert Works, discusses present practise in the design of three-phase power transmission systems. Written for designers and operators of these systems, the book affords, in brief compass, much practical, expert advice.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers cooperating with the Western Society of Engineers. The service is available only to their membership, and is maintained as a cooperative bureau by contributions from the societies and their individual members who are directly benefited.

Offices:—33 West 39th St., New York, N. Y.,—W. V. Brown, Manager.
53 West Jackson Blvd., Room 1736, Chicago, Ill., A. K. Krauser, Manager.
57 Post St., San Francisco, Calif., N. D. Cook, Manager.

MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to **EMPLOYMENT SERVICE, 33 West 39th Street, New York City,** *and should be received prior to the 15th day of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ELECTRICAL AND MECHANICAL ENGINEER, preferably graduate, under 40, experienced in design and manufacture of switches, fuses, panel boards, receptacles and similar electrical accessories, as general assistant to chief engineer of concern producing such devices. Should be willing and able to work at the board and handle small as well as big jobs. Opportunities. Apply by letter. Location, East. X-628.

SALES ENGINEER. Graduate of recognized engineering school to sell electrical measuring instruments and equipment to educational institutions. Some knowledge of electrical measuring instruments and methods required. Short period of training prior to sales work. Considerable traveling. Apply by letter, stating minimum salary and enclose recent photograph. Location, Pennsylvania. X-3361-C.

GRADUATE, electrical engineer, 27-30, familiar with public utility, electric transportation and general electrical engineering for promotional and editorial work. Permanent. Apply by letter. Location. East. X-3612.

MEN AVAILABLE

SUPERINTENDENT—ASSISTANT MANAGER, technical graduate, Fellow A. I. E. E., Member A. S. M. E., age 37, 15 years' experience in design, construction and operation of electric utilities, including generation, transmission and distribution. Have also actively engaged in power sales and public relations. Desires permanent position with opportunity for advancement. B-6794.

ENGINEER, technical graduate, 29, single. Fourteen years' experience, general testing, operation, construction and maintenance. Speak and write five languages. Now engaged in South America. Would prefer change to enterprising company operating in foreign countries where past experience would be of value and with future not limited to technical lines. Preference maintenance. Available in March. B-9611.

EXECUTIVE ENGINEER, A. S. M. E., A. I. E. E., 40, married. Business-minded engineering executive. Two Cornell degrees. Eighteen years power plant design, construction and operation, including four years residence in Cuba. Three years exporting and one year with large holding company. New York City preferred. A-3494.

ELECTRICAL ENGINEER, graduate of high grade electrical institute, 12 years' practical experience with manufacturing concerns and public utility, including eight years substation layout and relay protection, good theoretical knowledge of transmission line calculations. Desires position with leading public utility, as protection engineer or on transmission and distribution, research or investigation work. Preferred location, East, New York, or vicinity. B-8068.

GRADUATE ELECTRICAL ENGINEER, age 25, desires position in South America. Five years' experience industrial electrical engineering, substation and power house design and construction, underground distribution and so forth. C-2745.

ELECTRICAL ENGINEER, 20 years' experience as executive and engineer in construction and operation of electric lighting and power and street railway properties. Initiative and agressivness. Ability in organization and administration of these properties. Broad experience on construction, layout and design of transmission, distribution system, both aerial and underground, sub-station, etc. Available one month. B-6459.

MAINTENANCE ENGINEER, now available, technical graduate in electrical engineering. Experience covers installation and repairing of apparatus and operating in sub-stations and power stations. More recent experience in textile mills, as assistant to mechanical superintendent covering layouts for new work and changes including blower systems, lighting, power, heating and ventilating and general mill maintenance. B-3794.

ELECTRICAL ENGINEER, experienced in development design and manufacture of high grade electrical apparatus and instruments. Executive with broad experience. Thoroughly familiar with modern factory methods, organization and administration. American born Christian. B-2721.

ELECTRICAL ENGINEER, A. I. E. E., 27, married, graduate electrical engineer, four years' engineering experience; one year design and layout of substations; three years general engineering work in electrical engineering department of big public utility, including construction, system operation; desires new connection with contracting, managing or holding company or utility. Location Preferred, Great Lakes or Eastern States. C-3534.

MECHANICAL AND ELECTRICAL ENGINEER, 34, married, no children, 15 years' varied experience in factory management, plant design, construction and maintenance, telegraph (land and wireless) and telephone design and layouts. Desires change where head and hands are required. Location, anywhere. European, oriental experience. C-2151.

INDUSTRIAL ENGINEER, graduate engineer wishes to connect with manufacturers of foundry products for consultation with the view to standardizing equipment, manufacture, organization, cupola practise and wage incentives. Have had eight years' experience with large manufacturers and foundries throughout the country and can furnish very best references. B-6876.

ELECTRICAL ENGINEER, 44, technical graduate, licensed professional engineer, 12 years' experience as electrical designer (2½ years in charge of design) and 10 years' as assistant electrical engineer covering design, specifications, estimates, purchase of equipment and general technical and executive work for consulting and construction engineers on power plants, substations, and industrial plants. C-3785.

ELECTRICAL ENGINEERING GRADUATE, 26 years of age, married, desires a permanent position that will eventually lead to executive work in connection with railway electrification. Well trained in railway electrification problems and economics. Two years construction work, one year valuation work, Westinghouse graduate course. Location, immaterial, available 30 days' notice. C-3082.

EXECUTIVE ENGINEER. Experienced in supervision of design, construction, maintenance of buildings, shops, power plants, power transmission, distribution systems, equipment railway, power properties. Electrical and mechanical equipment installation, industrial plants, large mills, office buildings. Transportation and traffic studies; valuations. Studies manufacturing statistics, costs, processes, improvement, industrial plant arrangement, production methods. Engineering and financial investigations. B-5552.

ELECTRICAL ENGINEER, graduate with 10 years' experience in design and engineering of power and substations, all voltages. In charge of electrical design for industrial plants. Switchboard engineer with the Westinghouse. Public utility experience. Best of references. Location immaterial. C-3793.

GRADUATE ELECTRICAL AND MECHANICAL ENGINEER desires responsible position. Six years' university training and over fifteen years' active engineering experience. Now in charge of electrical engineering department of a public utility company. Design construction and operating experience. Also have had considerable steam engineering and purchasing experience. B-5842.

ELECTRICAL ENGINEER, 27, single, graduated 1925, including some advance work in Heaviside's Operators in engineering and advance Electro-statics, two years G. E. test course. Desires permanent position with public utility or manufacturing company. Employed at present but available on short notice. C-3762.

ELECTRICAL ENGINEER, B. S. in E. E., 1922. Graduate students course with large manufacturer, two years commercial work headquarters and three years district office same manufacturer. Desires connection company where quick advancement assured for maximum efforts. Available month's notice. Location preferred New York City. C-3802.

COLLEGE GRADUATE, 1925, B. S. in Electrical Engineering, desires position with an electrical contractor with an opportunity to learn the business. C-512.

SALES ENGINEER, ten years successful selling and sales promotion career desires connection with electrical manufacturer. Created demands on electrical merchandising items. Wide acquaintance with electrical jobbers, dealers, etc., throughout United States. Keen aggressive mind, convincing personality. Capable of creating enthusiasm in jobbers and salesmen. College graduate. Available January 1, 1928. A-968.

ELECTRICAL ENGINEER, 33, married, B. S., ten years' experience in design of power house, substation, industrial power and light, estimating and contracting. Desires position, location, New York City. At present employed. C-950.

ASSISTANT EXECUTIVE-ADMINISTRATIVE, 36, married, well balanced experience fifteen years covers: industrial surveys, cost analyses, commercial statistics, advertising, and administrative control. Seven years large company servicing subsidiaries and clients. Public utility experience. Prefers administrative or commercial to strictly technical. Location Preferred, New England, New York, B-9122.

HYDRO-ELECTRIC STUDENT ENGINEER, 24, single, R. P. I. graduate of E. E., two years' experience in civil engineering and construction, year and a half electrical testing and station designing. Wishes position which will give experience in hydro-electric construction, year and a half electrical testing and station designing. Wishes position which will give experience in hydro-electric construction and development field. Location immaterial. Available two weeks. C-2667.

ELECTRICAL ENGINEER, 5 years' experience, desires position in testings laboratory, or design of small electrical equipment and controllers. Industrial or special in nature. Developed executive ability, good draftsman, wishing to assume responsibility. Age 27, married. Available first of month. Salary, $2450. C-3804.

ELECTRICAL ENGINEER with executive ability, 38, fifteen years' experience construction, operation, maintenance, steam generating stations. Experienced in reconstructing and modernizing old plants. Speaks Spanish. Desires position Latin-America or foreign countries. C-1372.

ELECTRICAL ENGINEER, 35, married, graduate electrical engineer, German, 7½ years' experience as electrical engineer and master mechanic, handling Spanish labor in large mines and public utility companies in South America, desires responsible position requiring technical and executive ability. Location Preferred, South America. C-3672-710-C-1.

ELECTRICAL ENGINEER from a well known Middlewest University, age 23, specialist in Railway Engineering, desires experience with some electrical railway concern and to represent them in the future in his home country. Available at once. Location, New York or Philadelphia. C-3812.

ELECTRICAL ENGINEER, 24, married, recent graduate, desires position in commercial or engineering capacity. Experience in machine switching, telephone maintenance, Westinghouse graduate course, and sales correspondence. No preference as to location. Available on reasonable notice. C-3815.

ELECTRICAL ENGINEER, experienced utility meters, commercial and laboratory testing, accounting, drafting, teaching E. E.; good writer. Age thirty-four. B-8193.

ELECTRICAL ENGINEER, 39, technical graduate, desires position with progressive concern. Fifteen years' experience in construction, change-overs, maintenance, testing and plant engineering. Five years' with electric railways; two years construction of shipyards and shipbuilding; eight years papermaking industry. Considerable mechanical experience. Available on one month's notice. C-3331.

TECHNICAL GRADUATE, 28, with 7 years' experience in testing and service work and many types of electrical apparatus desires position with moderate size firm in some type of sales and service work. Willing to take a short period of sales training. Location Preferred, Northern New Jersey or Metropolitan District. C-3020.

ELECTRICAL ENGINEER, graduate, 31, married, 10 years' diversified experience designing, manufacturing and application of small special apparatus, such as regulators, timing devices, relays, etc. Some sales experience. Thoroughly familiar with management manufacturing plant. Desires position Electrical Engineer or assistant to executive of concern where hard work and ability to accomplish results will be recognized. C-3820.

YOUNG MAN, 29, married, electrical engineering degree, one year engineering office experience in Cuba. Now teaching electricity and mechanical drawing third year, desires to change to some line of work compatible with experience and offering year round employment. Present salary $200 a month. B-7028.

ELECTRICAL ENGINEER. The man you need as technical assistant in your management problems. Graduate engineer, 25, married, 4½ years' varied experience; G. E. Test; construction, maintenance, inspection and design on heavy electric traction equipment. Broad experience in industrial applications of electrical machinery. Business training. Paying investment for progressive concern. C-1048.

ELECTRICAL AND MECHANICAL ENGINEER, college graduate, young, single; thorough training manufacturing, drafting, G. E. Test, and engineering office. Three years responsible commercial appointment handling tenders and contracts at head office; five years large electrical and steam turbine manufacturers (British associated company), desires post with scope for initiative, mechanical or electrical. Preference commercial work where sound technical knowledge necessary; or undertaking requiring immediate or eventual representation Great Britain or continent Europe. Excellent knowledge French. C-3803.

DESIGNING ENGINEER, 40, married, engineer in charge of steam of hydro-electric power station or substation design or on general engineering work relating to public utilities. Qualified to act as resident engineer or superintendent of construction. B-7779.

ELECTRICAL ENGINEER, 28, single, graduate, 2 years General Electric Test department, 1 year requisition and complaint work, 2 years contract and sales on lighting fixtures and radios. Location Preferred, anywhere. B-9090.

ELECTRICAL ENGINEER, office and field experience, familiar with operation, construction and design public utility steam and hydro-electric generating stations, transmission line calculations, laboratory, field and factory testing. Industrial power applications and maintenance in plants and buildings. Have been resident and office, engineering firm. In charge engineering office public utility. C-3587.

ELECTRICAL DESIGNING ENGINEER, in charge of large four year construction program of Eastern New York utility, involving 4, 13.2, 44 and 110 kv. stations now about completed. Ten years in charge of designs of switchboards and switch arrangements, and four years design of high speed circuit breakers and industrial switches with largest Eastern manufacturer. German technical graduate. Desires permanent position where his experiences are valuable. C-3835.

AGENTS REPRESENTATIVES

ENGINEER as New York representative or manufacturer's agent; also office or desk room for rent, completely furnished. Will rent for a long or short period. Very centrally located. Telephone, stenographic and drafting room facilities. C-3828.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held October 5 and November 2, 1927, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary

To Grade of Fellow

SEARING, EMERY DEFOREST, Advisory Engineer, Portland Electric Power Co., Portland, Oregon.

SIMONS, DONALD M., Development Engineer, Standard Underground Cable Co., Pittsburgh, Pa.

To Grade of Member

AMY, ERNEST V., Engineer, Radio Corporation of America, New York, N. Y.

CAVALCANTI, ANTONIO E. DE A., Chief Electrical Engineer, Paulista Railway Shops and Water Dept., Paulista, Jundishy, Brazil, S. A.

COLEMAN, HARRY C., Manager of Marine Engineering, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

CREIM, B. W., Electrical Engineer, Modesto Irrigation District, Modesto, Calif.

FERANDEZ-MAREQUE, Francisco, Electrical Engineer, Paraguay Central Railway, Paraguay, So. America.

FLUCK, AARON C., Senior Field Engineer, Braden Copper Co., Chile, S. A.

FRAMPTON, ARTHUR H., Assistant Electrical Engineer, Hydro Electric Power Comm., Toronto, Ont., Canada.

GREGORY, WILLIAM H., Assistant Electrical Engineer, Public Works Dept., Shannon, N. Z.

GRIMES, JAMES H., Special Representative, Westinghouse Elec. Int. Co., Chile, S. A.

HANNON, J. WALTER, General Supt. of Plant, Indiana Bell Telephone Co., Indianapolis, Ind.

HUND, AUGUST, Electrical Engineer, U. S. Bureau of Standards, Washington, D. C.

KINNARD, ISAAC F., Electrical Engineer, General Electric Co., West Lynn, Mass.

KLINE, C. HOWARD, Assistant Engineer, General Electric Co., Pittsfield, Mass.

LARSEN, C. J., Consulting Engineer, Automatic Electric, Inc., Chicago, Ill.

MARSHALL, NORMAN, Mfg. and Consulting Engineer, Bridgeport, Conn.

McANGE, WILLIAM N., President, Inter-Mountain Telephone Co., Bristol, Tenn.

McCULLOUGH, PHILLIP M., Vice President and Chief Engineer, Mexican Telephone & Telegraph Co., Mexico, D. F. Mexico.

NOBLE, PAUL O., Engineer in charge D-c. Apparatus Dept., General Electric Co., Fort Wayne, Indiana.

ORCUTT, GUY H., Electrical Engineer, Michigan Alkali Co., Wyandotte, Mich.

TILLOTSON, C. C., Electrical Engineer, United Verde Copper Co., Clarkdale, Arizona.

VANDERVOORT, GERALD A., General Supt., N. B. E. P. Comm., St. John, N. B., Canada.

WATERS, JAMES S., Instructor in Electrical Engineering, Rice Institute, Houston, Texas.

WEST, HARRY R., Electrical Engineer, General Electric Co., Pittsfield, Mass.

WINTERER, HORACE K., Commercial Engineer, General Electric Co., Los Angeles, Cal.

WRIGHT, PAUL L., Member of Technical Staff, Bell Telephone Labs., New York.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before December 31, 1927.

Anderson, E. F., General Electric Co., Schenectady, N. Y.
Arnold, E. E., Bureau of Power & Light, Los Angeles, Calif.
Baker, H. H., Royal Indemnity Co., New York, N. Y.
Baldwin, G., 1105 State St., Erie, Pa.
Balet, J., E. L. Phillips & Co., Rockville Centre, N. Y.
Bate, H. R. C., Mazapil Copper Co., Ltd., Aranzazu, C. del Ore, Zacatecas, Mex.
Batten, W. B., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Bauer, P. S., Harvard University, Cambridge, Mass.
Beales, J. T., Jr., Beales Radio Elec. Co., San Anselmo, Calif.
Bell, D. T., University of Cincinnati, Cincinnati, Ohio
Benson, A. W., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Bernard, W., Habirshaw Cable & Wire Corp., Yonkers, N. Y.
Billings, P. A., General Electric Co., West Lynn, Mass.
Binnie, W. C., Consolidated Mining & Smelting Co., Chapman Camp, B. C., Can.
Boggs, J. I., Mountain States Tel. & Tel. Co., Denver, Colo.
Bollow, A. J., Jr., General Electric Co., Schenectady, N. Y.
Bonanno, J. L., Radio Corp. of America, New York, N. Y.
Brown, G. H., New York Edison Co., New York, N. Y.
Brunner, C. A., Consolidated Gas & Electric Co., Baltimore, Md.
Bryant, W. L., Jr., General Electric Co., Schenectady, N. Y.
Buehner, R. O., American Steel & Wire Co., Waukegan, Ill.
Burrall, H. S., Brooklyn Little Theatre, Brooklyn, N. Y.
Carlson, C. P., Bell Telephone Laboratories, Inc., New York, N. Y.
Carnegie, A., Pennsylvania Power & Light Co., Youngstown, Pa.
Carpenter, L. G., (Member), Consulting Engineer, Denver, Colo.
Carrion, R. E., National Railways of Mexico, Mexico City, Mex.
Cate, C. L., (Member), Consulting Engineer, Montreal, P. Q., Can.
Champlain, C. H., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Chiles, J. H., Jr., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Clapp, N. B., Jr., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Clark, A. M., General Electric Co., Buffalo, N. Y.
Cohn, B. E., University of Denver, Denver, Colo.
Conlon, R. F., Rochester Gas & Electric Corp., Rochester, N. Y.
Connor, J. F., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Conrad, R. W., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Cook, W. L., Reliable Electric Co., Chicago, Ill.
Cooley, O. R., Vulcanite Portland Cement Co., Easton, Pa.
Donardo, J. D., Western Electric Co., Newark, N. J.
Deresienski, A. S., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Donkin, B., General Electric Co., Schenectady, N. Y.
Dufault, J. A., Tennessee Utilities Commission, Chattanooga, Tenn.
Durgin, R., General Electric Co., West Lynn, Mass.
Eames, H. F., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Eaton, T. O., General Electric Co., Schenectady, N. Y.
Edscorn, G. E., Wagner Electric Corp., St. Louis, Mo.
Eidem, E. L., Public Service Co. of No. Illinois, Chicago, Ill.
Elliott, D. A., Columbia University, New York, N. Y.
Evjen, H. M., California Institute of Technology, Pasadena, Calif.
Fairburn, A. J. B., Cooper Union, New York, N. Y.
Farnlof, C. G. T., Electrical Engineer, New York, N. Y.
Finnen, W. J., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Fishman, S., Newark College of Engineering, Newark, N. J.
Fortier, R. L., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Fuller, M. W., Victor Talking Machine Co., Camden, N. J.
Garthus, I. B., Northern States Power Co., Minneapolis, Minn.
Goold, H. P., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Gottschall, S. E., New York University, New York, N. Y.
Gribble, A. J., General Electric Co., Schenectady, N. Y.
Grumbly, W. T., New York Edison Co., New York, N. Y.
Haendler, A. T., Edison Elec. Illuminating Co. of Boston, Roxbury, Mass.
Hagen, A. M., Standard Underground Cable Co., Perth Amboy, N. J.
Hagenguth, J. H., General Electric Co., Pittsfield, Mass.
Halstead, G. W., Jr., General Electric Co., Schenectady, N. Y.
Hampe, G. W., Commonwealth Edison Co., Chicago, Ill.
Hart, E. A., Pacific States Electric Co., Los Angeles, Calif.
Hartman, F. C., General Electric Co., Schenectady, N. Y.
Harvey, W. C., Consolidated Mining & Smelting Co. of Canada, Ltd., Trail, B. C., Can.
Heathcote, H. P., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Herrick, W. J., Westinghouse Elec. & Mfg. Co., Springfield, Mass.
Hesse, A. N., New York Edison Co., Bronx, New York, N. Y.
Hochmiller, C., Stone & Webster, Inc., Boston, Mass.
Hood, H. C., (Member), Pittsburgh Transformer Co., Pittsburgh, Pa.
Howe, K. L., Westinghouse Elec. & Mfg. Co., Seattle, Wash.
Johnson, J. K., Columbia University, New York, N. Y.
Kennedy, L. P., General Electric Co., Pittsburgh, Pa.
Kenny, B. M., Scarboro Hydro-Electric System, Birch Cliff, Ont., Can.

King, B. L., Bruce Bros., Syracuse, N. Y.
Kleist, M. R., Armour Institute of Technology, Chicago, Ill.
Kratzer, J. J., Lehigh Portland Cement Co., Allentown, Pa.
Kreig, H. C., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Langdon, H. J., Electrical Engineer & Contractor, Victoria, B. C., Can.
Langord, A. M., Duquesne Light Co., Pittsburgh, Pa.
Langguth, P. O., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Lawrence, J. H., (Member), Thomas E. Murray, Inc., New York, N. Y.
Leerburger, F. J., Duquesne Light Co., Pittsburgh, Pa.
Licht, H. M., Williams Hardware Co., Streator, Ill.
Lindsay, R. W., Mountain States Tel. & Tel. Co., Denver, Colo.
Lissman, M. A., Western Precipitation Co., Los Angeles, Calif.
Little, C. S., General Electric Co., Buffalo, N. Y.
Longobardi, B. G., New York Edison Co., New York, N. Y.
Lowry, L. R., Bell Telephone Laboratories, Cliffwood, N. J.
Lutgen, C. J., Brooklyn Edison Co., Brooklyn, N. Y.
Lyons, J. M., General Electric Co., West Lynn, Mass.
MacCarthy, D. D., Cornell University, Ithaca, N. Y.
Martin, H. T., Harlem Valley Electric Corp., Pawling, N. Y.
Merry, R. E., General Electric Co., Schenectady, N. Y.
Messier, W. J., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Metcalf, C. N., New York Edison Co., New York, N. Y.
Meuren, W. H., Rola Company, Oakland, Calif.
Mitra, S. K., General Electric Co., Schenectady, N. Y.
Moore, S. E. Chester Valley Electric Co., Coatesville, Pa.
Murphy, Howard E., Stone & Webster, Inc., Boston, Mass.
(Applicant for re-election.)
Murphy, M. E., Bell Telephone Laboratories, Inc., Chicago, Ill.
Newhouse, H. E., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Newton, E. T., American Brass Co., Waterbury, Conn.
Nickerson, O., General Electric Co., Chicago, Ill.
Noyes, J. A., Turner Falls Power Co., Turner Falls, Mass.
Null, F. E., Western Union Telegraph Co., New York, N. Y.
O'Dwyer, J. M., Southern Sierras Power Co., Riverside, Calif.
Owen, R. H., General Electric Co., Denver, Colo.
Parsons, R. B., Narragansett Electric Lighting Co., Providence, R. I.
Pettyjohn, J. G., General Electric Co., Schenectady, N. Y.
Powell, R. W., General Electric Co., Schenectady, N. Y.
Rei, P. F., 3675 Broadway, New York, N. Y.
Richardson, H. J., (Member), Snow Mfg. Co., Los Angeles, Calif.
Robinson, A. A., Taylor-Wharton Co., High Bridge, N. J.
Roney, C. E., Westinghouse Elec. & Mfg. Co., Minneapolis, Minn.
Rush, P. E., University of Pittsburgh, Pittsburgh, Pa.
Sabbagh, E. N., Michigan State College, East Lansing, Mich.
Sack, J., 122 Lincoln Ave., Central Falls, R. I.
Salvatori, H., Geographical Research Corp., New York, N. Y.
Schaelchlin, W., (Member) Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Schaffer, E. J., General Electric Co., Fort Wayne, Ind.
Sedgwick, A. F., Central Hudson Gas & Electric Corp., Kingston, N. Y.
Shults, J. E., Maintenance Co., New York, N. Y.
Small, W. H. H., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Smalley, M. F., Ohio Power Co., Canton, Ohio
Smith, H. B., General Electric Co., Erie, Pa.
Smith, L. W., English Electric Co. of Canada, St. Catharines, Ont., Can.
Smith, R. E., Public Service Co. of No. Illinois, Chicago, Ill.
Solodoff, V. J., Westchester Lighting Co., Mt. Vernon, N. Y.
Spanbauer, R. J., General Electric Co., Buffalo, N. Y.
Stevens, C. V., Locke Insulator Corp., Pittsburgh, Pa.
Taylor, J. B., Appalachian Electric Power Co., Lynchburg, Va.
Tipton, E. W., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Towner, O. W., Bell Telephone Laboratories, New York, N. Y.
Trevino, G. L., (Member), Mexican Tel. & Tel. Co., Mexico City, Mexico D. F., Mex.
von Ahn, A. J., Enterprise Electric Co., San Francisco, Calif.
Wallis, C. M., General Electric Co., Lynn, Mass.
Wallis, C. W., General Electric Co., Lynn, Mass.
Warth, S., Southern Bell Tel. & Tel. Co., Jackson, Miss.
Weedfall, W. W., Southeastern Bell Tel. Co., Dallas, Texas
Wentz, E. C., Westinghouse Elec. & Mfg. Co., East Pitsburgh, Pa.
Williams, W. R., Northern States Power Co., Minot, No. Dakota
Wilsey, K. C., New York Edison Co., New York, N. Y.
Winter, F. E., General Electric Co., Schenectady, N. Y.
Wise, R. O., Bell Telephone Laboratories, Inc., New York, N. Y.
Wiswall, I. W., Westinghouse Elec. & Mfg. Co., East Springfield, Mass.
Woll, W. M., No. Indiana Public Service Co., Hammond, Ind.
Wood, J., Jr., 206 E. 36th St., New York, N. Y.
Young, G. S., Kansas City Power & Light Co., Kansas City, Mo.
Total 152.

Foreign

Coulthard, W. B., Government Technical Institute, Insein, Burma, India
Milward, F. A., Public Works Dept., Gov't. of Burma, Rangoon, Burma, India
Scobie, J. K., Municipal Council, Shanghai, China
Sen, A. K., Russa Engineering Works, Ltd., Delhi, India
Total 4.

STUDENTS ENROLLED

Algeo, Bradley C., Jr., Swarthmore College
Allen, Cecil S., Mississippi Agri. & Mech. College
Allenson, James H., Rhode Island State College
Anderson, Harry B., Rensselaer Polytechnic Inst.
Andes, Earl T., University of Missouri
Andrews, Robert W., University of Florida
Ankenman, Earl B., Kansas State Agri. College
Arnold, H. Roys, University of Colorado
Aucock, Clifford T., Clarkson College of Tech.
Awtrey, Merrill E., Georgia School of Technology
Backus, Frank H., West Virginia University
Baker, Pled P., University of Kentucky
Baker, Robert C., Mississippi Agri. & Mech. College
Ball, George A., Brooklyn Polytechnic Institute
Ball, J. Wesley, Mississippi Agri. & Mech. College
Bankerd, Edward A., University of California
Barnes, Thomas B., University of Kentucky
Barre, Henry J., Kansas State Agri. College
Barrett, Theodore L., Rose Polytechnic Institute
Barzilaski, Peter M., Bucknell University
Bates, William W., Drexel Institute
Baugh, Charlie R., University of Kentucky
Baughman, John S., Carnegie Institute of Tech.
Beach, Gordon L., University of Wisconsin
Beacham, Hardy R., North Carolina State College
Becker, Addison J., University of Colorado
Belle Isle, Armand G., Syracuse University
Benderman, John O., University of Tennessee
Berkley, Leland S., Mississippi Agri. & Mech. College
Berry, James F., University of Notre Dame
Bingenheimer, Melvin, University of Oklahoma
Binneweg, A., Jr., University of California
Bird, George T., Georgia School of Technology
Bird, J. LeGrand, Rensselaer Polytechnic Inst.
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NOTES OF THE INDUSTRY

The Parker-Kalon Corporation, manufacturers of self-tapping and drive screws used for fastening name plates to electrical apparatus, announces the removal on December 1, of its factory and general offices to 200 Varick Street, New York.

The Hazard Manufacturing Company, manufacturers of electrical wires and cable, announces the removal of its New York office to the Transportation Building, 225 Broadway. The Chicago office has been moved to the Midland Building, 168 W. Adams Street. The New York office and warehouse of the Hazard Wire Rope Company, manufacturers of wire rope and wire rope fittings, now separate and distinct from the Hazard Manufacturing Company, will be retained at 533 Canal Street. The Chicago office and warehouse will be retained at 32 So. Clinton Street.

Across-the-Line Starting Switches.—The Electric Controller & Manufacturing Company, Cleveland, are now supplying their standard type ZO across-the-line starting switches for small a-c. motors in iron clad tanks, which makes them suitable for operation in atmospheres where acid fumes are present. Like the standard EC&M type ZO starting switch, all of the contacts including the overload trip, open and close under oil so that this starter is flame-proof.

New Shell Type Lincoln Motors.—The Lincoln Electric Company of Cleveland, Ohio, manufacturers of "Stable-Arc" welders and "Linc-Weld" Motors, has just perfected a squirrel cage motor for use in various kinds of wood working machinery and all other machinery requiring high speed motors. This motor is of the so-called shell type, an all-welded design, and is made to the standard dimensions of the trade. It is supplied in two sizes, 3 HP and 5 HP. Both motors are manufactured for either two or three phase, 60 cycle current and a speed of 3600 R. P. M. The stator is composed of laminated sections arc-welded together. The rotor is also entirely arc-welded and provided with either a straight or tapered bore.

Large Westinghouse Unit for Japan.—The Tokio Electric Light Company of Japan recently placed, through the Westinghouse Electric International Company, an order with the Westinghouse Electric and Manufacturing Company for one 25,000 Kw. turbine generator. The unit will be built at the South Philadelphia Works of the latter company and installed in the new extension of the Senju Power Plant. The Senju Power Plant is a steam standby station, located just outside the City of Tokio. This unit will be of the same design as two machines installed there in 1925, and will bring the capacity of the station up to a total of 75,000 Kw.

Sterling Electric Motors, Inc. Organized.—Carl E. Johnson, formerly vice-president of the U. S. Electrical Manufacturing Company, has organized the Sterling Electric Motors, Inc., Los Angeles, to manufacture a new line of electric motors and motor specialities. Property has been purchased, and plans and specifications drawn for a modern daylight factory which will be in operation next January. Associated with Mr. Johnson as officers of the new corporation and in the active management are J. M. Sharp, Earl Mendenhall, Allen A. Adams, and Horace S. Walling, who were formerly president, chief engineer, superintendent and sales engineer respectively of the U. S. Electrical Manufacturing Company.

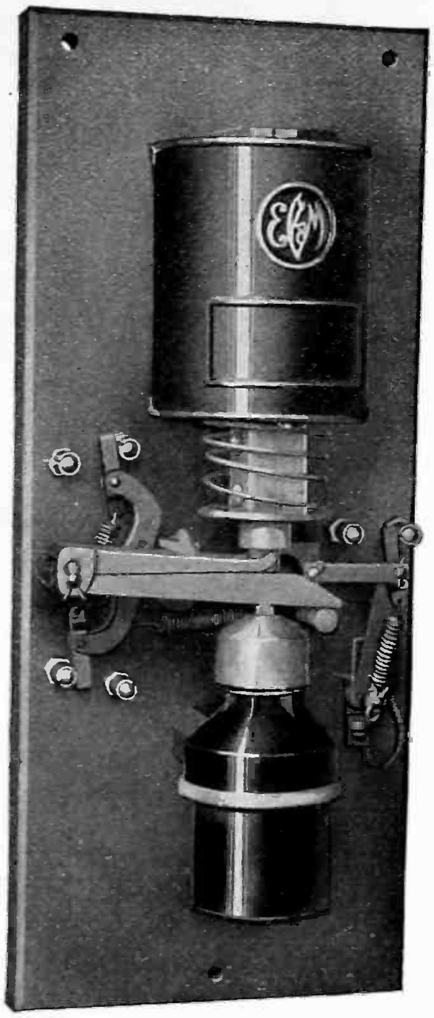
Ohio Brass Creates New York Executive Branch.—In recognition of the constantly increasing growth of the utility and industrial interests which are concentrated in the eastern states, the Ohio Brass Company has decided to create an executive branch in New York City, covering New England and the territories served by their present New York and Philadelphia sales offices.

It is anticipated that the establishment of this executive branch will better enable the company to serve the industry in the broad sense and will develop a more intimate relationship with this large center of utility and industrial activity. This change will be made effective about the first of the year with Mr. Frederic Attwood in charge. Mr. Attwood is well known in the electrical industry, both here and abroad, having directed the interests of the Ohio Brass Company in Europe for several years and has recently returned to this country to undertake the organization and direction of the New York executive office.

60,000 Kilowatt Turbine-Generator for Birmingham.—The first giant single-cylinder turbine-generator for service south of the Mason and Dixie Line is now being manufactured in the Schenectady shops of the General Electric Company. Rated at 60,000 kilowatts, this unit will be the initial installation in a new station being built by the Dixie Construction Company near the site of the present Gorgas station of the Alabama Power Company near Birmingham, Ala. The ultimate capacity of the station will be 240,000 kilowatts, and will be used to meet the fast growing load demand of the south.


KERITE
In 1752 Franklin invented the Lightning Conductor and identified lightning and electricity. A century later, Day invented
KERITE
Over half a century of experience has identified it as the most reliable and permanent insulation for Electrical Conductors
DAYS KERITE
KERITE INSULATED WIRE & CABLE COMPANY
NEW YORK CHICAGO

An Accurate Time Delay Relay



THIS new relay operates to open a circuit or to close a circuit after a predetermined time interval, which may be as long as two minutes. The timing is adjustable for any period throughout the operating range of the relay.

The time delay is secured by the escapement of mercury through an orifice and is very accurate. No dash pots are used, no pendulums, no clock-work. Temperature changes do not affect the operation or accuracy.

Type HG Relays are made for operation on alternating or direct current circuits.

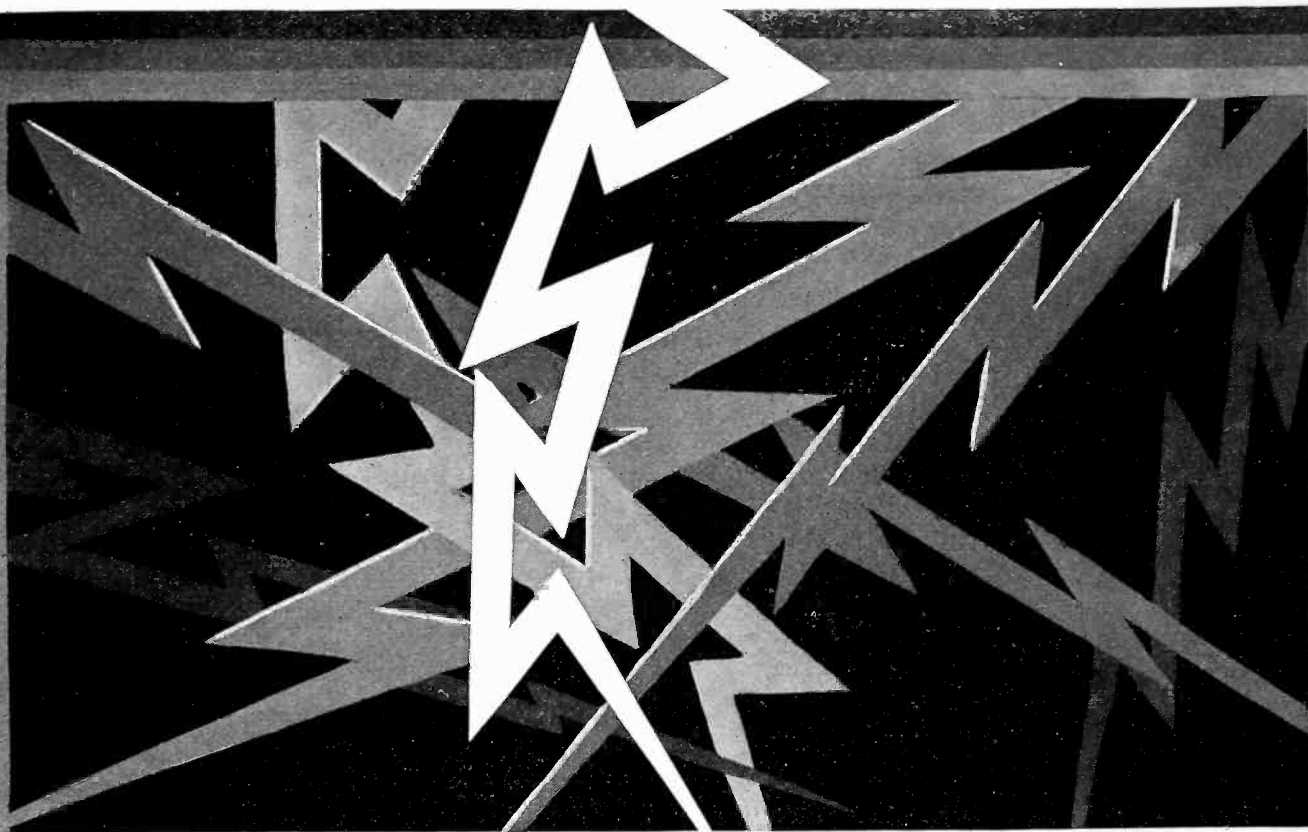
Type HG Relays have many applications. They are used with synchronous motor starters for controlling the DC field contactor. They are used with automatic skip hoist controllers for holding the skip stationary in the dumping position for several seconds to permit it to discharge its load; for introducing a delay in the sequencial starting or stopping of an interlocked conveyor system; and, in fact, for any service requiring an accurate and dependable time delay relay.

Send for Specification Sheet S-26

THE ELECTRIC CONTROLLER & MFG. CO.

CLEVELAND, OHIO

NEW YORK-50 CHURCH ST.
CHICAGO-CONWAY BLDG.
DETROIT-DIME BANK BLDG.
BIRMINGHAM-BROWN-MARX BLDG.
CINCINNATI-1ST NATIONAL BANK BLDG.
LOS ANGELES-912 E. THIRD ST.
SALT LAKE CITY-228 SO. W. TEMPLE
TORONTO-REFORD BLDG.
PHILADELPHIA-WITHERSPOON BLDG.
PITTSBURGH-OLIVER BLDG.
SAN FRANCISCO-CALL BUILDING
MONTREAL-DRUMMOND BLDG.
TULSA-217 E. ARCHER ST.

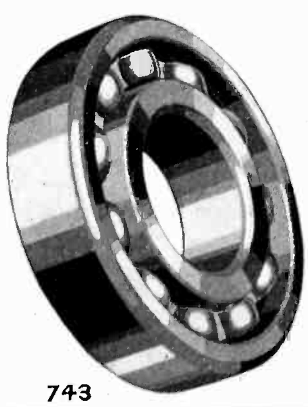


Why You Should Specify New Departures

BECAUSE of their better steel, greater precision, least possible friction, maximum capacity for combined radial and thrust loads, New Departure Ball Bearings give the longest service for lowest maintenance cost in electric motors.

Write for "Cutting Your Costs" and Booklet "K." . . . Sent on Request

THE NEW DEPARTURE MANUFACTURING COMPANY
Chicago BRISTOL, CONNECTICUT Detroit
San Francisco



743

New Departure Quality Ball Bearings

ON WINTER NIGHTS

—when the mercury goes away down—when snow, sleet and ice attack the overhead lines—when underground cable gives way—comes a test, a real test of electrical insulating materials. It pays to use the best.

Minerallac Insulating Compounds were developed to meet these severe winter conditions. They are moisture-resistant and will not shrink at all working temperatures. Impartial tests show no cracks, fissures or checks at below freezing point.

These characteristics are always found in Minerallac Insulating Compounds Nos. 78, 104 and 104-A—combined with high dielectric strength values.

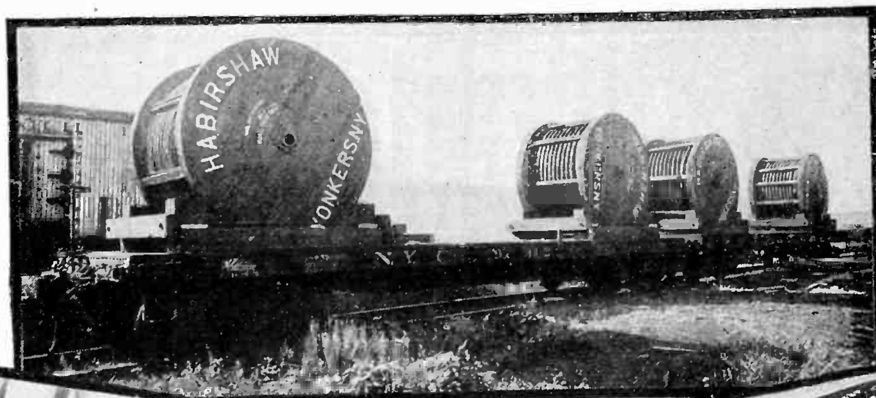
MINERALLAC ELECTRIC COMPANY

1043-1045 Washington Boulevard **Chicago, Illinois**

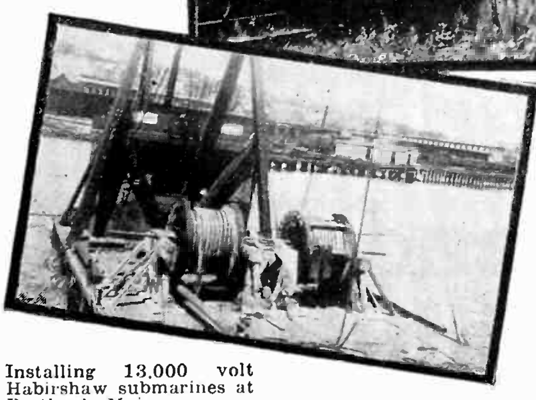
MINERALLAC

HABIRSHAW
YONKERS, N.Y.

Always associated with the best



Habirshaw 33,000 volt cables en route to St. Louis, Mo.



Installing 13,000 volt Habirshaw submarines at Portland, Maine.

Dredging a trench for 22,000 volt, Habirshaw submarines at Pittsburgh, Pa.

Reliability of Habirshaw Paper Cable nowhere better illustrated

The repeated selection of Habirshaw Paper Cable for submarine installations is conclusive evidence of its reliability.

For it is obvious that the bottom of the river is no place to lay any but the most dependable type of cable.

Guard against the contingency of future trouble by specifying Habirshaw Paper Cable for submarine installations.

HABIRSHAW CABLE AND WIRE CORPORATION

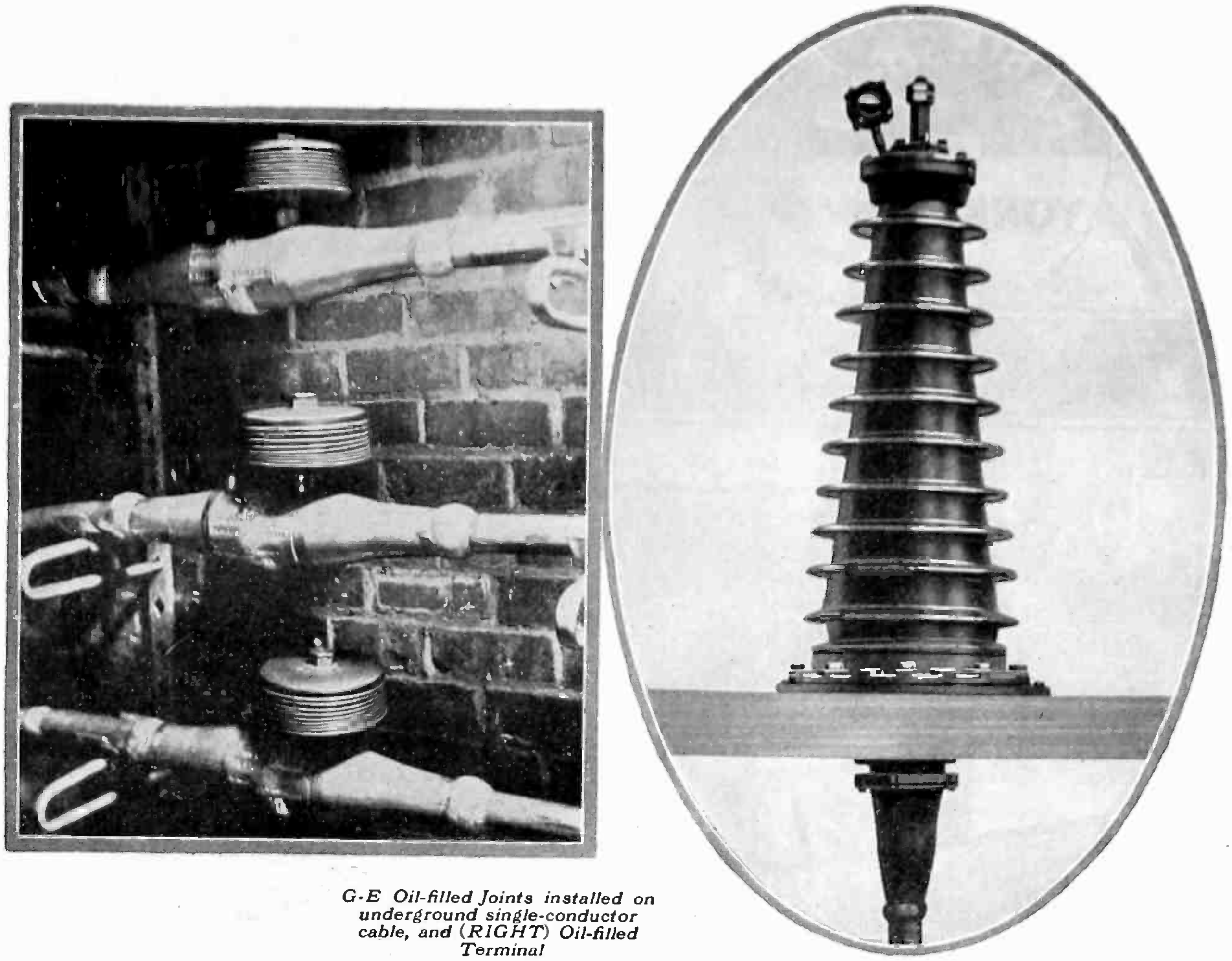
10 East 43rd Street, New York City

Plants: Yonkers, N. Y.—Bridgeport, Conn.—Nepperhan, N. Y.

HABIRSHAW

PROVED BY THE TEST OF TIME

Paper Insulated Cable — Varnished Cambric Insulated Cable — Armored Cable — Rubber Insulated Cable



G-E Oil-filled Joints installed on underground single-conductor cable, and (RIGHT) Oil-filled Terminal

Oil-filled Joints and Terminals *for* extra high-tension cable

In line with its development of high-voltage cable, General Electric introduces these new cable accessories—

—which have a break-down strength in excess of that of the cable;
—which are mechanically strong and electrically permanent;
—and which are easily installed—a 66-kv. joint is completed in less than 8 hours.

These joints and terminals are operating successfully at voltages ranging from 33 kv. to 75 kv. More than 1200 joints are in use on circuits of 66 kv. and higher.

They provide a means of connecting oil reservoirs to the cable—a decided advantage. The use of reservoirs is recommended.

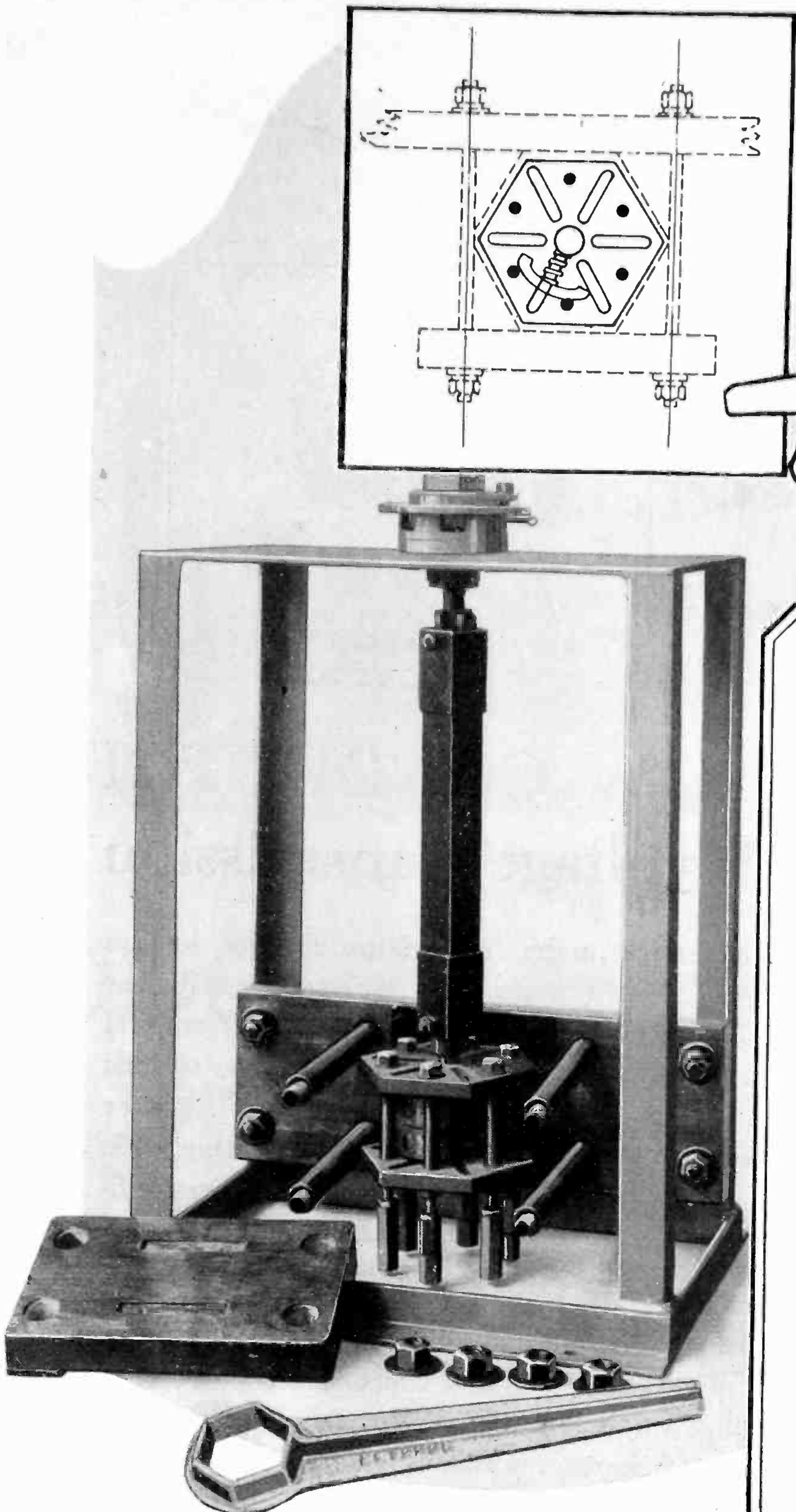
Standard G-E Insulated Wires and Cables are giving uninterrupted, efficient service to central stations and industrial plants the world over. They can be relied upon to withstand the most severe operating conditions.

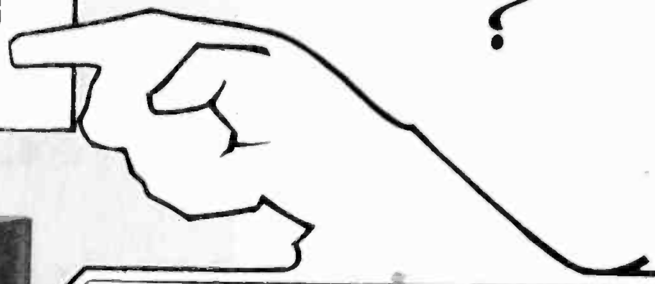
810-3

GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., SALES OFFICES IN ALL PRNCIPAL CITIES

*"What are the advantages of this tap changer"?





Replying to C.K.*
Re: Tap Changer

The rugged construction, simplicity and adequate insulation of this tap changer are evident from the accompanying photograph. It has a rotating action and—as shown by plan diagram—this tap changer has surface contact instead of line contact to assure ample carrying capacity. It is self-cleaning—there is sufficient pressure and shearing action to remove any sludge from the contacts.

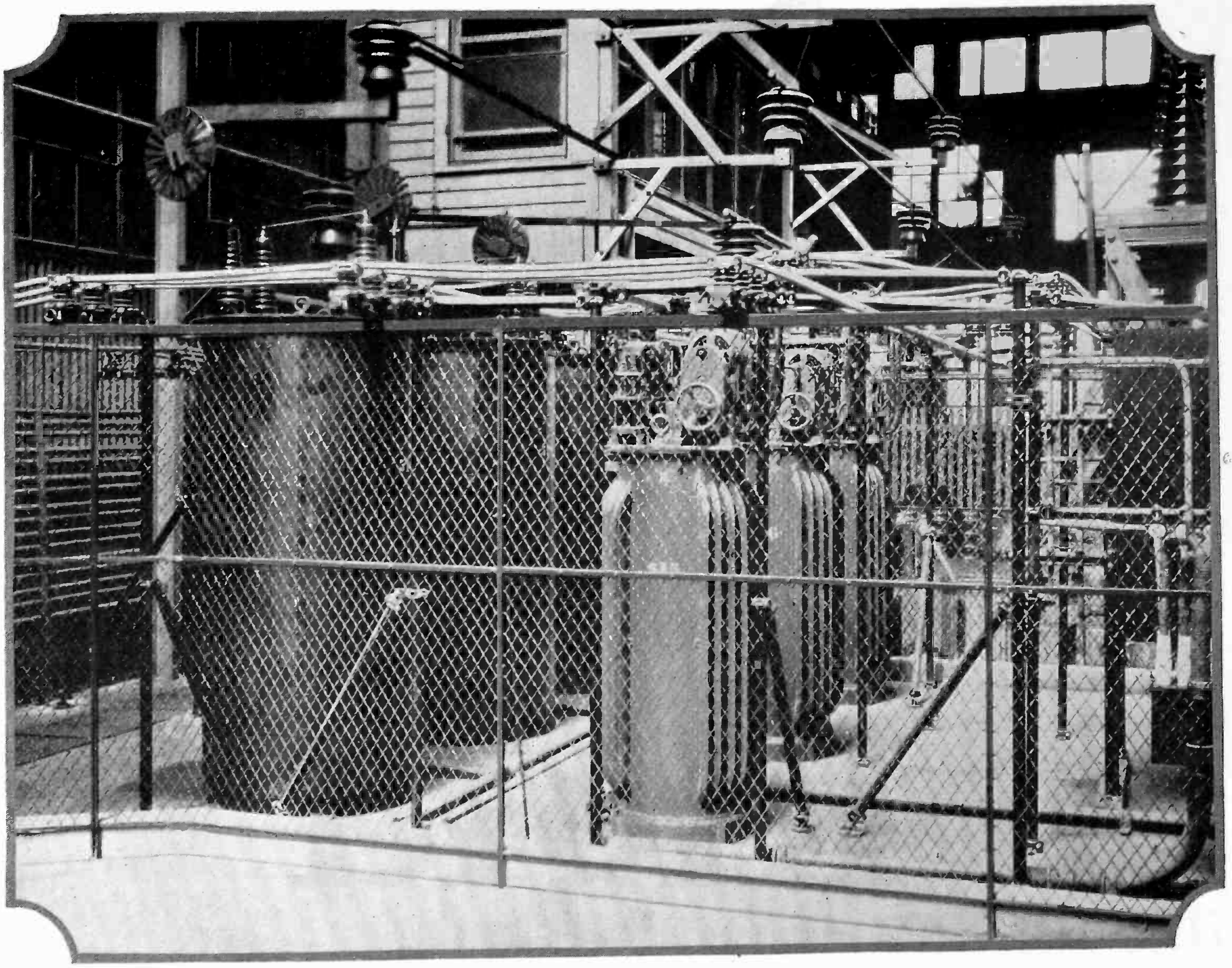
The tap changer has been made as proof against error and tampering as possible. The operating lever which extends through the transformer lid can be firmly locked on any tap—but not between taps. The dial at all times indicates the particular tap in service.

This is one of a series of answers to important questions frequently asked us regarding transformer design, construction and operation.

KUHLMAN TRANSFORMERS

KUHLMAN ELECTRIC CO., Bay City, Michigan

Akron.....High and Barges Sts.
Atlanta.....411 Glenn Bldg.
Boston.....69-71 High St.
Buffalo.....280 Carolina St.
Chicago.....844 Rush St.
Cincinnati.....1308 Union Trust Bldg.
Cleveland.....627 Union Trust Bldg.
Dallas.....Unit 2, Santa Fe Bldg.
Denver.....1843 Wazee St.
Detroit.....3-260 Gen. Motors Bldg.
Greensboro, N. C.....333 S. Davie St.
Indianapolis..202 Indiana Ter. Whse.
Los Angeles 316 American Bank Bldg.
Milwaukee.....1031 Clybourn St.
Minneapolis.....1004 Marquette Ave.
Montreal....415 Canada Cement Bldg.
New York.....Graybar Bldg.
Oklahoma City.....1013 Braniff Bldg.
Omaha.....923 W. O. W. Bldg.
Philadelphia.....1700 Walnut St.
Pittsburgh.....839 Oliver Bldg.
Saint Paul.....1479 Blair St.
Salt Lake City..134 West 2d South St.
San Francisco.....Call Bldg.
Seattle.....314 Seneca St.
Toledo.....424 Spitzer Bldg.
Washington.....1328 New York Ave.
York, Pa......335 W. Market St.



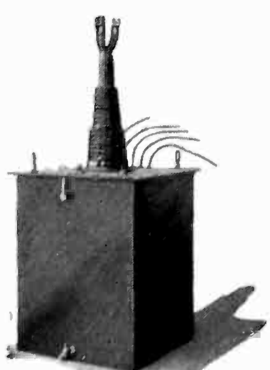
Manufacturers Sell by Test

Hundreds of manufacturers test their products with American Transformer equipment,

To be sure their products meet claims, that quality of products is uniformly maintained.

Among them are manufacturers of electrical and allied equipment including:

Insulators	Magnetos	Glass Insulators	Generators
Varnish	Oil	Compounds	Mica
Bushings	Lamps	***PAPER CABLE**	Appliances
Paper	***CABLE**	Transformers	Cable Joints
Wire	Fixtures	Rubber Gloves	Cambric
			Instruments

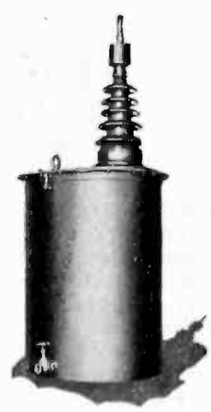


Loading Transformer

*The installation of American Testing Transformers shown above is used for testing high voltage cable at the plant of the Okonite-Callender Cable Co., Passaic, N. J.

Other similar installations have been made for the Simplex Wire and Cable Company; Standard Underground Cable Company; John A. Roebling's Sons Company; the Kerite Insulated Wire Company and many other wire and cable companies.

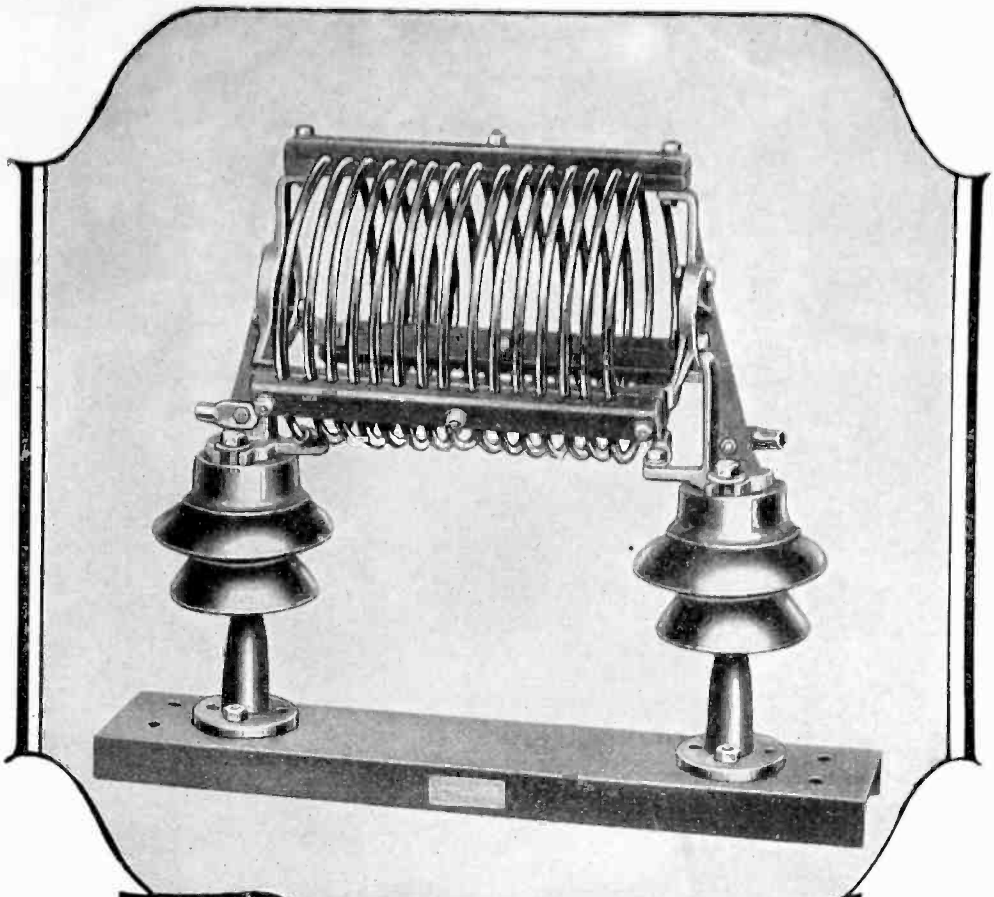
Manufacturers have come to depend upon American Transformers. You can do likewise with the fullest confidence.



High Voltage Transformer

Bulletin 1035-J illustrates and describes 16 types of testing transformers. Send for a copy.

AMERICAN TRANSFORMER CO., 176 Emmet St., NEWARK, N. J.



Rigid

G-E choke coils are mechanically RIGID. They are braced to stand the heaviest short-circuit forces—the buffeting of wind and weather in any locality.

—RIGID because they are braced at the points where the stresses come.

—RIGID because the coil itself, the maple spreaders, the copper-alloy spiders and end-brackets, the insulators, and bases are all bolted together to form a single mechanical unit.

With G-E lightning arresters they provide all that is possible in permanent protection.

G-E choke coils are made for all ratings, both in insulated and line suspension types. All channel bars, insulator caps, and pins are galvanized. All insulated types are furnished with two-bolt terminals.

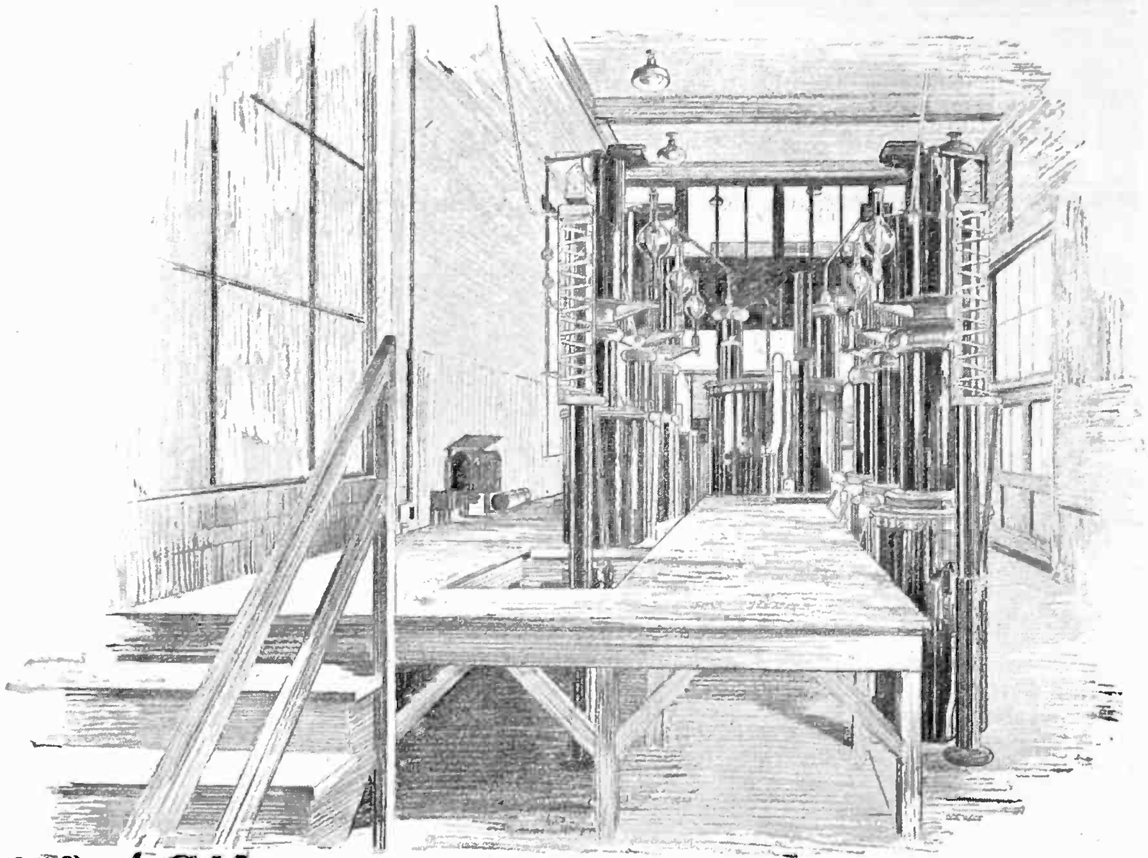
For detailed information ask for publication GEA-50A

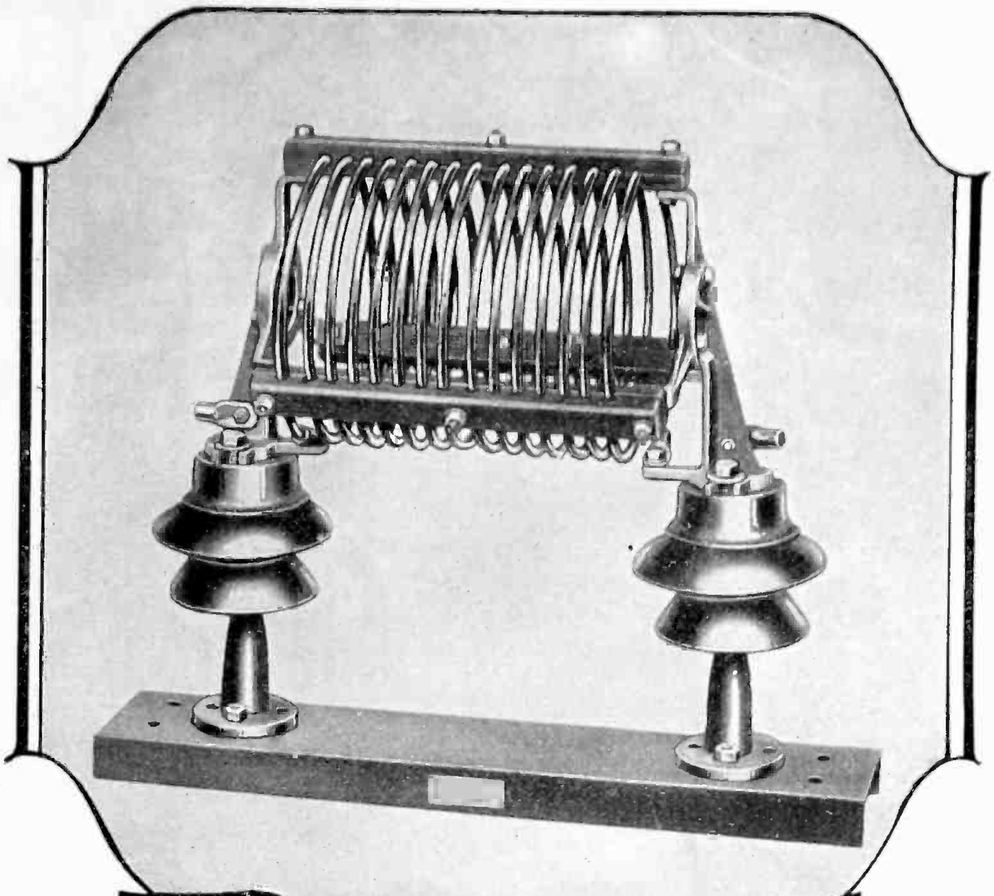
No matter what G-E product you are considering, you can be sure that it has the dependability for which G E apparatus is noted. In the choke coil the controlling factor is mechanical strength—therefore the G-E Choke Coil is made RIGID, to meet the worst conditions of service.

442-7

GENERAL ELECTRIC

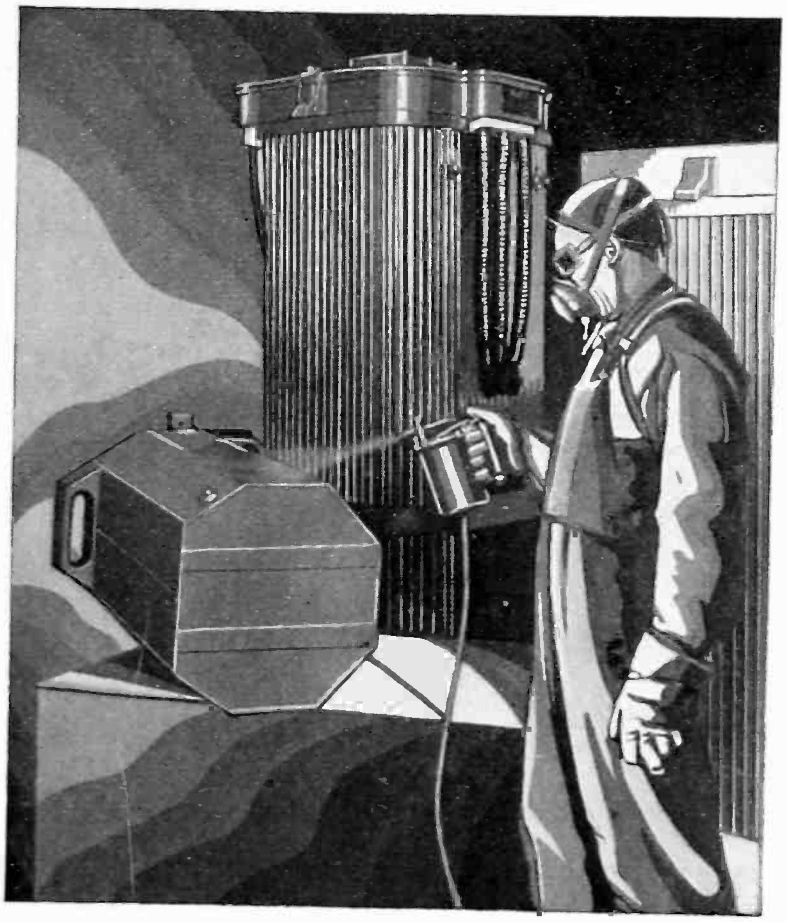
GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., SALES OFFICES IN PRINCIPAL CITIES





PRODUCTS

MOTORS—Single, Polyphase and Fynn-Weichsel Motors TRANSFORMERS—Power, Distribution and Instrument
FANS—Desk, Wall and Ceiling types



Spray gun method of painting transformer cases with battleship gray paint. Note iron skids on bottom of the case.

Skids . . .
provide protection against corrosion

Each Wagner Distribution Transformer is provided with skids welded to the bottom of the tank. These skids protect the bottom of the transformer tank and make it easy to slide the transformer from one place to another.

The skids are painted but the paint is merely for the sake of appearance. In fact, you can slide a Wagner Transformer over a concrete floor until all the paint on the skids is removed, yet the skids will afford protection against oil leakage due to the rusting away of the bottoms of transformer tanks.

This is only one of the many refinements in Wagner Transformer Design . . . one of the many little things which mean so much in the way of added strength, durability, performance and continuity of service.

6737-7

Write for Bulletin 148

WAGNER ELECTRIC CORPORATION—6400 Plymouth Avenue—St. Louis, U. S. A.

SPECIFICATIONS:—*Types F-8, F-19 and F-9: Standard capacities 15,000 or 25,000 volts. Estimated interrupting capacity 18,000 to 30,000 amperes at 15,000 volts. For truck type or platen mounting.*

CONDIT

1230

Service

Service is your business and ours. The manufacture, transmission, and distribution of power is essentially a service—a service which means more in comfort and convenience than any other we enjoy. In the few years since its inception, the power industry has established and maintained the highest standards of service.

Because of that, Locke Insulators, with a record of satisfactory performance made over a long period of years on many of the most important transmission lines of the world, are your logical selection. Exacting standards, constant research, and rigid manufacturing control, assure a finished product of consistently high quality.

You can rely on Locke Insulators to always give you the perfect service necessary to the maintainance of your high standards.

LOCKE INSULATOR CORPORATION
BALTIMORE MARYLAND

Since 1894 the name Locke has been synonymous with quality in insulators. This consistently high quality is, in this age of service, more essential than ever.

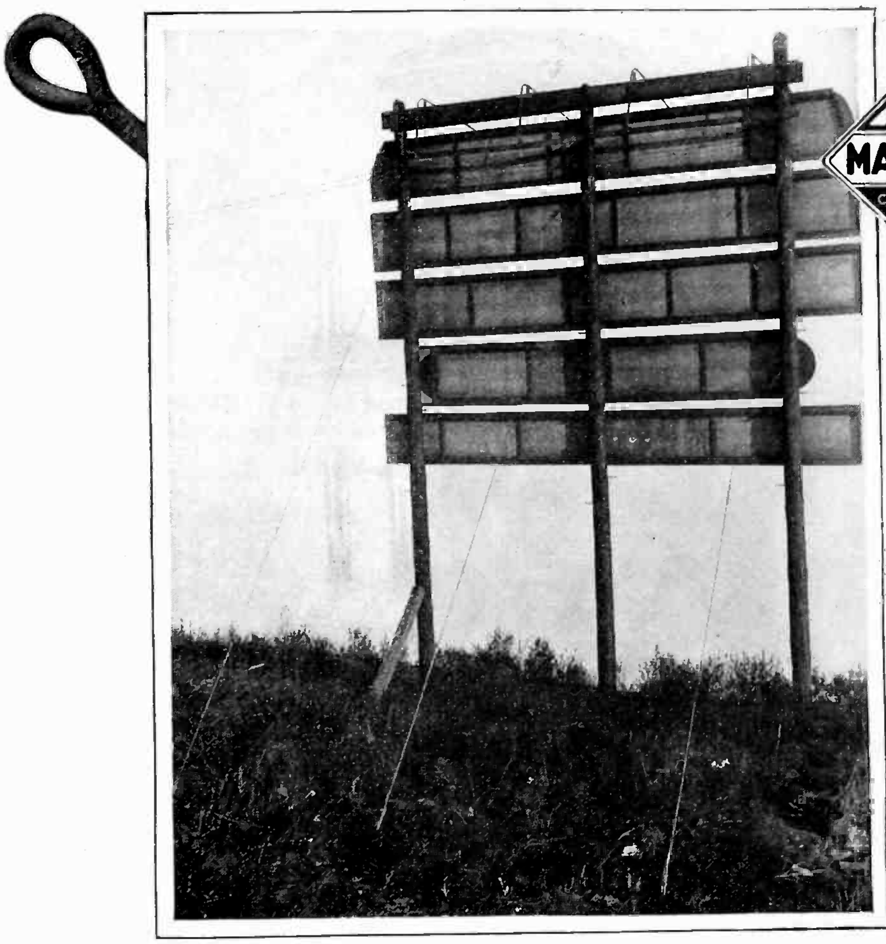
For assured service under any and all conditions specify "Locke."

LOCKE R=∞

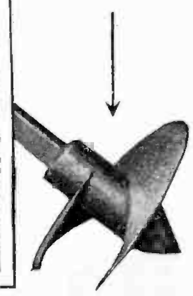
LOCKE PORCELAIN

ESTABLISHED 1894

LOCKE QUALITY LOCKE SERVICE



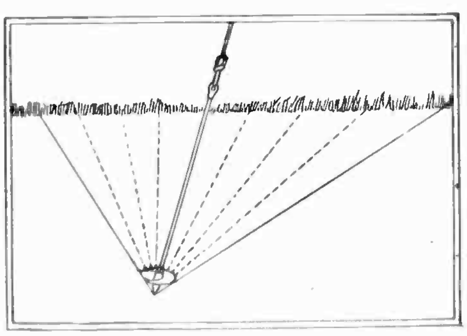
Look for "SCRULIX" on the Helix



Holding in Sand

Against Tremendous Windage Strain

On the banks of the Mississippi, directly opposite the Cahokia Plant, below East St. Louis, is a large electric warning sign for steamboats. With ordinary anchoring methods this sign pulled loose several times due to the large windage surface and the sandy ground in which it was erected. Months ago this sign was anchored with three No. 1200 Matthews Scrulix Anchors. They have held this sign through several near tornadoes and have not slipped an inch.



The helix of Matthews Scrulix Anchors is so designed that under strain, the lines of force radiate from the anchor helix at 45° angles so that hundreds of cubic feet of earth hold the anchor in place. This principle in Matthews Scrulix Anchors gives a tremendous holding power in comparatively soft earth.

113

This great holding power is due to the design of Matthews Scrulix Anchors. The lines of force radiate from the Helix at 45 degrees so that hundreds of cubic feet of earth and tons of resistance help to hold the anchor in place.

These anchors reach your men all assembled, ready to install. They are made in seven sizes to meet every anchoring need. Send for Bulletin 801 that contains interesting informative data which will help you solve your anchoring problems.

Your Electrical Distributer Will Be Glad To Serve You On Matthews Products

W. N. MATTHEWS CORPORATION

Engineers and Manufacturers

3706 FOREST PARK BLVD. ST. LOUIS, U. S. A.

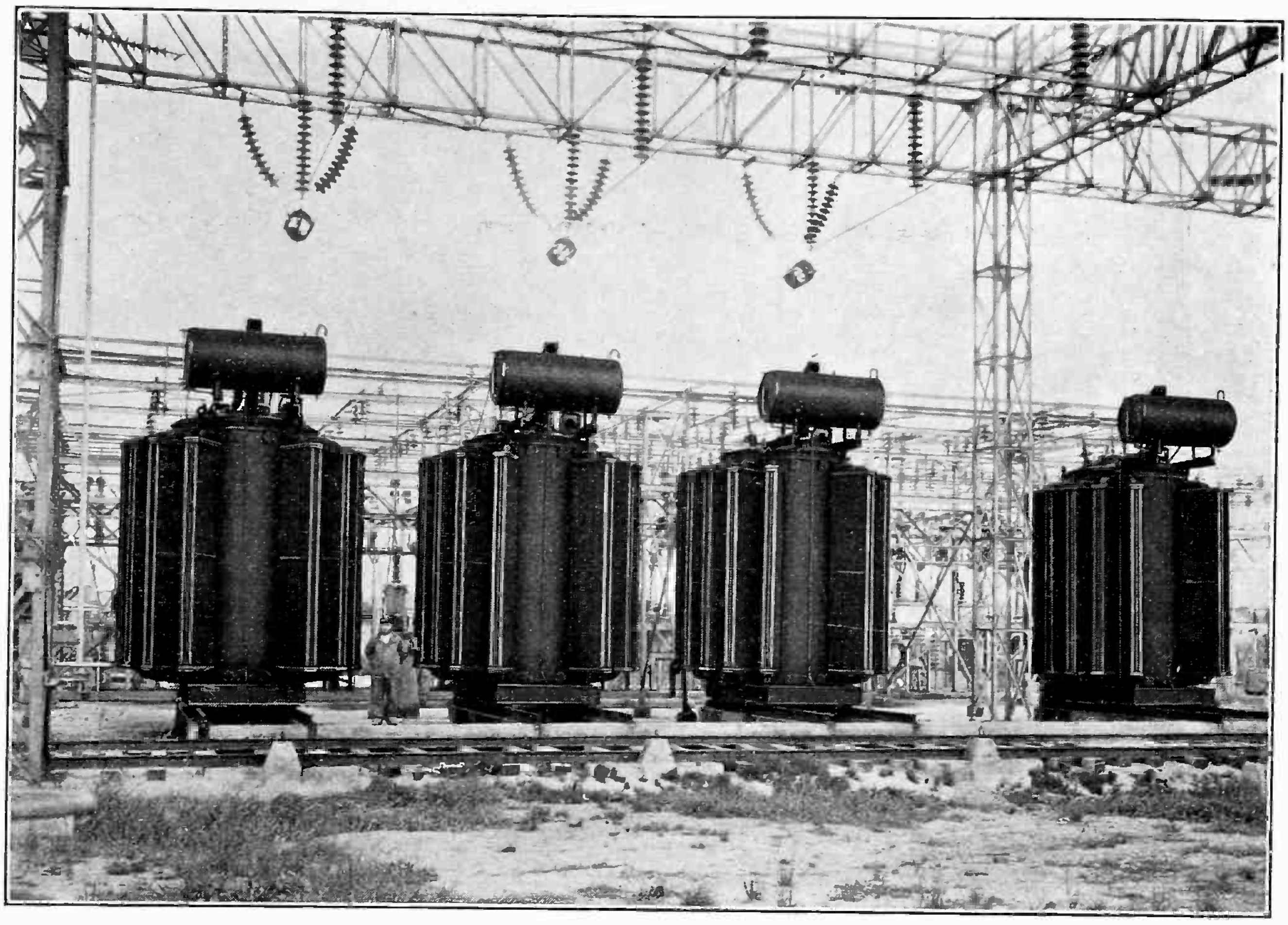
Offices In All Principal Cities

MATTHEWS

SCRULIX ANCHORS

Look for "**SCRULIX**" *on the Helix*

ALLIS-CHALMERS



ANOTHER INSTALLATION OF ALLIS-CHALMERS POWER TRANSFORMERS

Above is shown the Racine Sub-Station of the Milwaukee Electric Railway and Light Company where there are installed Four 10,000 KV-A., 76300/132000 Y Volts HV., 27600 Volts LV., 60 Cycle, 1 Phase, Oil Insulated, Self-Cooled, Out-Door Type Transformers.

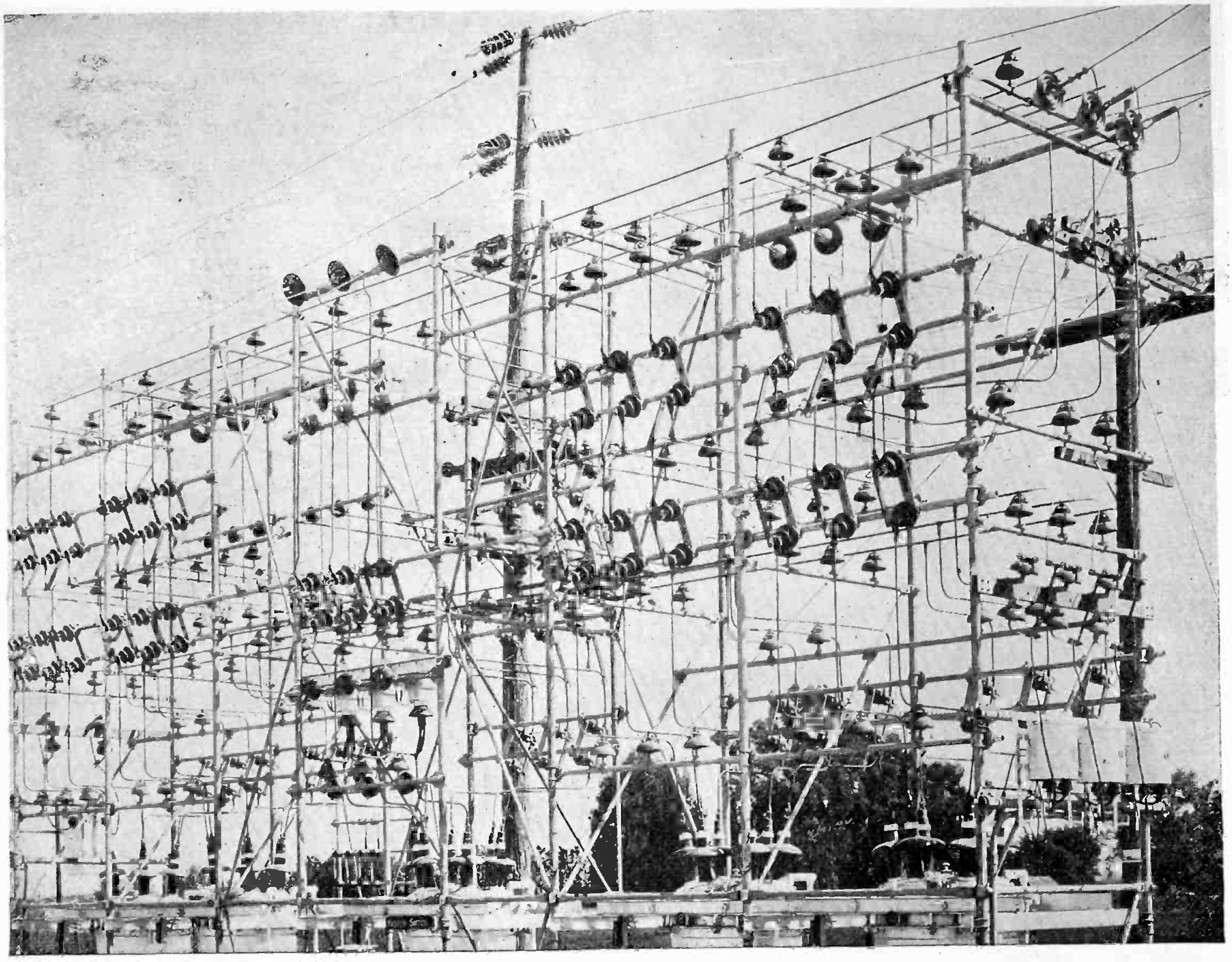
These Transformers also are rendering unquestionable service.

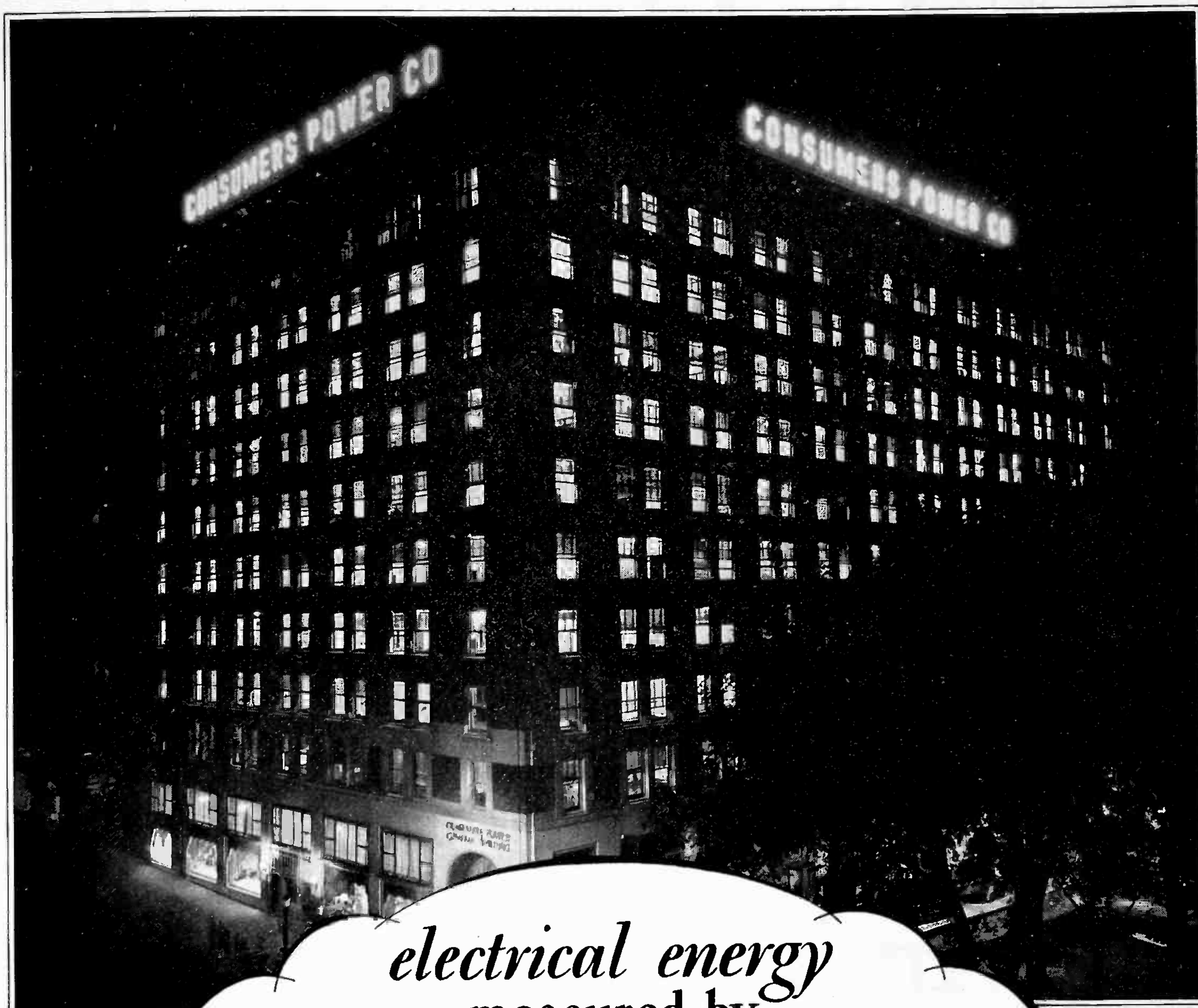
ALLIS-CHALMERS PRODUCTS
Electrical Machinery
Steam Turbines
Steam Engines
Gas and Oil Engines
Hydraulic Turbines
Crushing and Cement Machinery
Mining Machinery

ALLIS-CHALMERS MANUFACTURING COMPANY

MILWAUKEE, WISCONSIN. U.S.A.

ALLIS-CHALMERS PRODUCTS
Flour and Saw Mill Machinery
Power Transmission Machinery
Pumping Engines-Centrifugal Pumps
Steam and Electric Hoists
Air Compressors - Air Brakes
Agricultural Machinery
Condensers





electrical energy
measured by

SANGAMO METERS

AND TIME TOLD BY SANGAMO CLOCKS

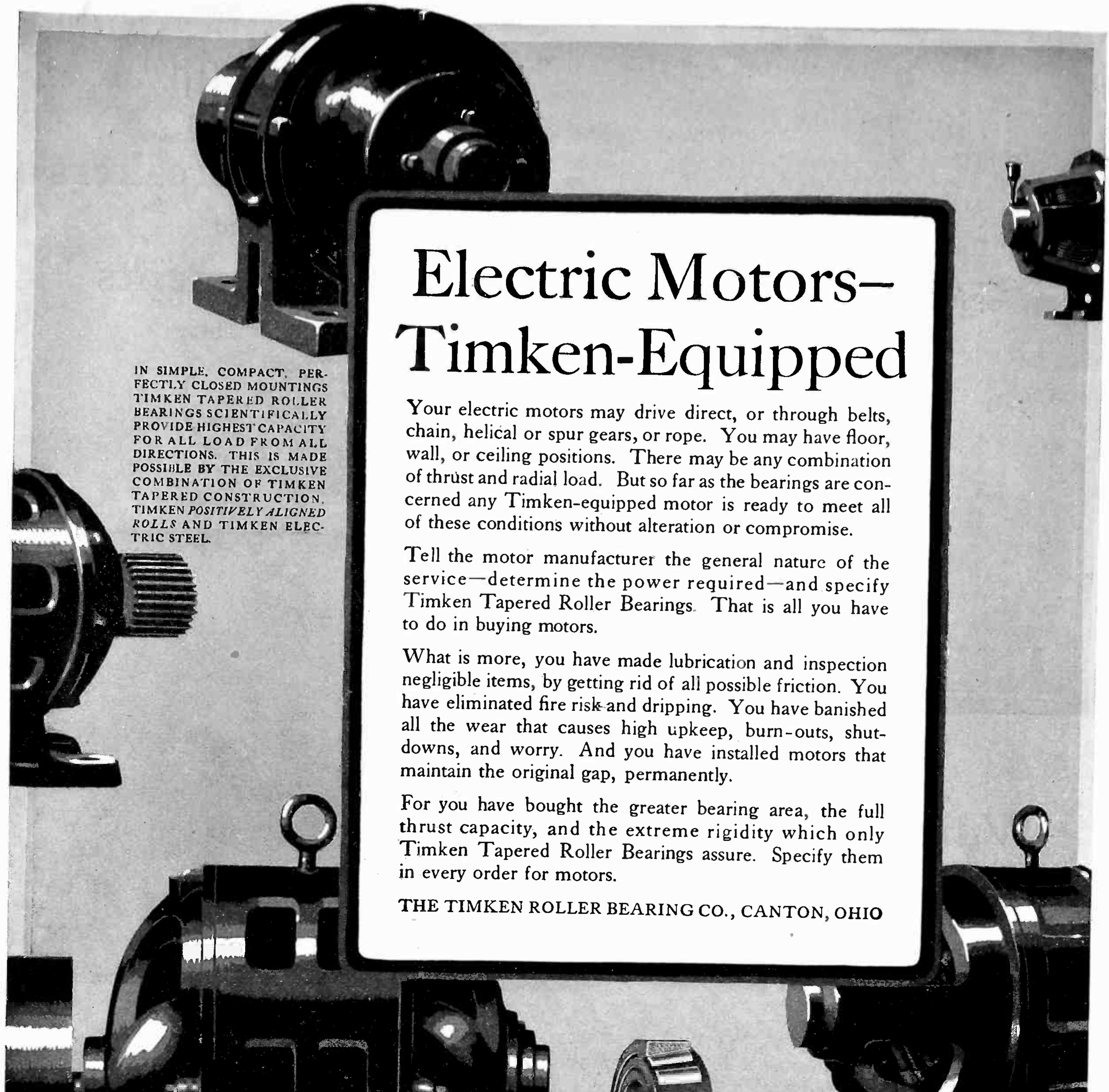
The new Consumers Power Company Building, Jackson, Mich.—one of the largest erected this year by any public utility—is completely Sangamo equipped.

The electrical energy is measured by Sangamo Meters and electrically wound Sangamo Clocks are installed throughout.

It is the first building to have a battery of Sangamo Clocks—guaranteed to keep time with the accuracy of railroad watches.

The problem of measuring electrical energy and the energy factors that enter into the cost of furnishing electric service is the main problem of Sangamo engineers. As a result of their endeavors, there is a Sangamo Meter for every service-measuring purpose, and somewhere in the world there is a Sangamo Meter installed every twelve seconds of every working day.

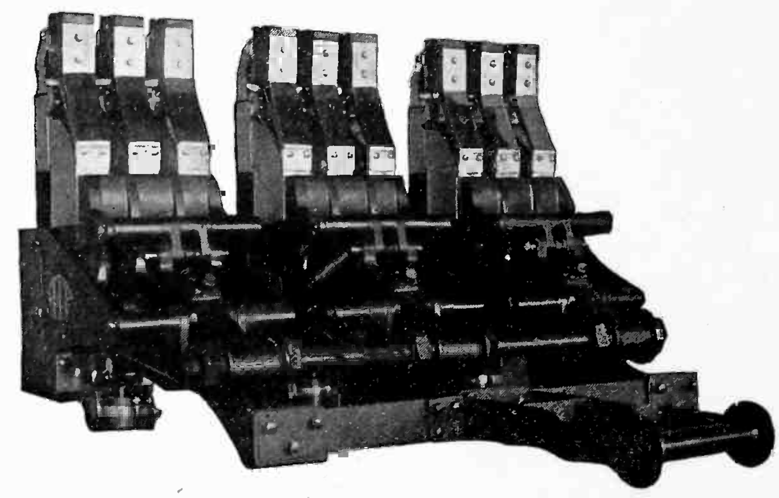
SANGAMO ELECTRIC COMPANY, SPRINGFIELD, ILLINOIS



TIMKEN *Tapered Roller* **BEARINGS**

Immersed in AIR

for SAFETY AND RELIABILITY



A PROMINENT CHICAGO INSTALLATION

A 5000 ampere I-T-E type L G Circuit Breaker for 600 volts or less alternating current service. This breaker is equipped with Overload, Dalite (direct acting inverse time limit), and Autoite (non-closable on overload) features.

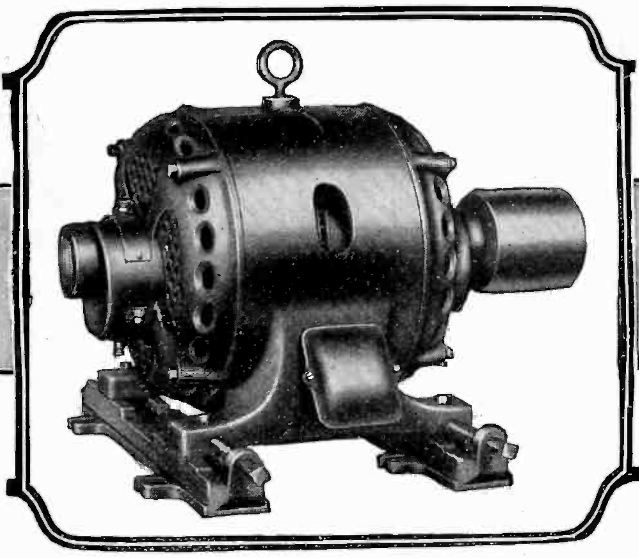
I-T-E AIR BREAK has definite advantages not present in the oil breaker

1. No oil—to leak, carbonize, burn or explode—Just air.
2. No tanks to conceal anything—or the lack of it.
3. No cells—nothing which needs or deserves to be imprisoned—Just a faithful and efficient servant.
4. Inherent simplicity—with resulting low cost of installation and maintenance.

THE CUTTER COMPANY—EST. 1888—505 N. 19th STREET—PHILADELPHIA

CUTTER

U-RE-LITE I-T-E CIRCUIT BREAKERS



30 Horse Power Century Type SC Squirrel Cage Induction 3 and 2 Phase Motor

Continuity of Service

The long uninterrupted service which users of Century Type SC Squirrel Cage Induction 3 and 2 Phase Motors experience, results from liberal proportions, with proper mechanical and electrical design and allocation of active materials.

Additional desirable features which contribute to their "Keep a-Running" ability are:

1 . . Armatures are practically indestructible. The copper bars and end rings are brazed over an area approximately six times their cross section.

2 . . Bearings last under severe service. They are made from cast phosphor bronze, machined to micrometer limits—and provided with machine-cut figure-8 oil grooves.

3 . . Field coils withstand the dampness of humid, tropical climates because they are insulated with moisture resisting material and the completed winding saturated with insulating compound.

Century Type SC Squirrel Cage Induction 3 and 2 Phase Motors are built in all standard sizes from ¼ to 75 horse power. Under normal operating conditions temperature rise is not more than 40° Centigrade.

CENTURY ELECTRIC CO. ✓✓ *1806 Pine Street* ✓✓ ST. LOUIS

33 Stock Points in the United States and More Than 50 Outside Thereof

"They Keep — Century MOTORS — a-Running"

¼ to 75 H. P. ¼ to 75 H. P.

FIBREX TREE WIRE

Where trees must not be trimmed

A typical Fibrex installation in New England

Where hazards are greatest - places where trees must not be trimmed and where wires are rubbed and chafed by swaying limbs - splice in a piece of Fibrex Tree Wire.

Central Stations find that Fibrex creates good will by eliminating the short circuits and swinging grounds that interfere with the maintenance of steady voltage.

Short pieces of Fibrex spliced into the line will afford ample protection where overhead lines must run through trees.

Fibrex consists of a rubber insulated copper conductor protected by successive layers of tape, tarred jute, non-metallic Fibrex armor and a wear-resisting weatherproof braid.

An immediate check-up along the line and the early installation of Fibrex at danger points will save the repair gang many annoying and expensive emergency calls.

SIMPLEX WIRE & CABLE Co

MANUFACTURERS

201 DEVONSHIRE ST., BOSTON

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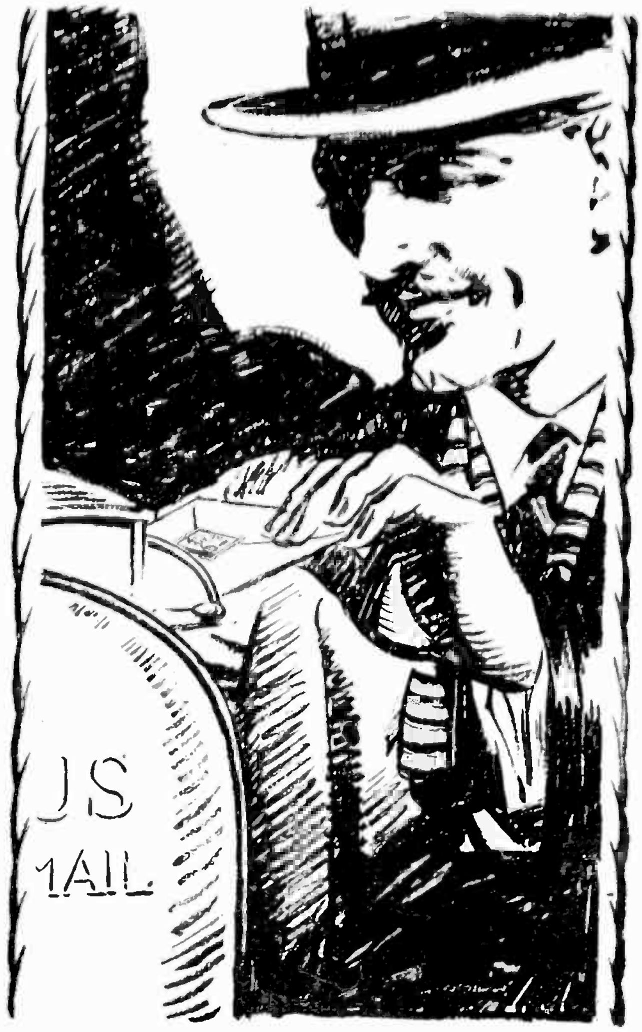

MAIL THAT CHECK

for Christmas Seals today

HAS your local tuberculosis association mailed some Christmas Seals to you? Why should you keep them?

Here's the answer: Christmas Seals help finance the Tuberculosis Associations. These associations have already aided in cutting the tuberculosis death rate by more than half. Every seal you buy works directly for the health of your community, your friends, your family—your health.

Send that check to your local association today. Put the seals on your Christmas mail—on your Christmas packages—and spread their message of health and happiness.

THE NATIONAL, STATE, AND LOCAL TUBERCULOSIS ASSOCIATIONS OF THE UNITED STATES

Holabird & Roche, Chicago, Architects
George A. Fuller Co., Chicago—New York, General Contractors
J. Livingston & Co., Chicago, Electrical Contractors

The STEVENS HOTEL, Chicago

Wired Throughout with

American Steel & Wire Company's Rubber Covered Wire

TWO million feet of rubber covered wire were used to completely wire all of the 29 floors, 3000 guest rooms, several kitchens, ballrooms, banquet and meeting rooms, hallways, reception parlors, lobbies and other parts of this magnificent new hotel recently completed on Michigan Boulevard, Chicago. Only the very finest material and the most rigid specifications were approved for this great building. The selection, therefore, of our wire to meet these demands expresses most forcefully the uniform and dependable quality of the product, and further gives striking evidence as to the standing with leading architects and contractors.

Let us send you our indexed catalog and handbook of electrical wires and cables. Estimates furnished promptly from any of our offices in all of the principal cities.

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		WORCESTER	94 Grove Street
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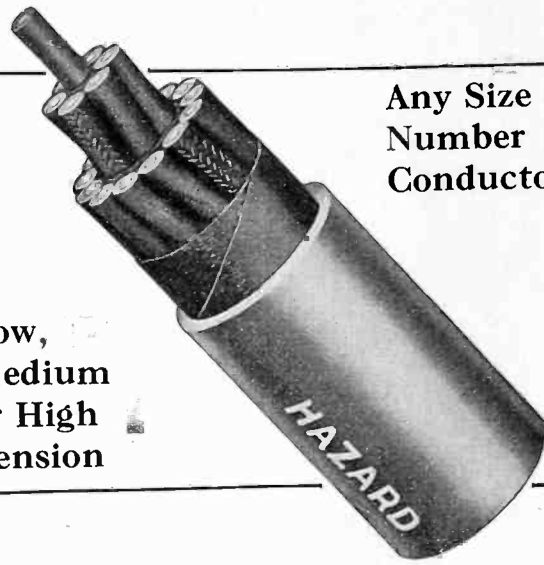
Protection

—FOR—

Important Circuits



Any Size or Number of Conductors

Low, Medium or High Tension

Hazard Standard Lead Encased Cables meet the demand for underground cables of an exceptionally high quality.

Their high dielectric strength is obtained from the use of Hazard Standard Insulation—our highest grade of rubber compound.

The lead sheath is of uniform thickness and tightly formed about the core.

Send for Book No. 67 giving specifications and other data.

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Lapp Insulators do not fail!

LAPP INSULATOR CO., Inc.
LE ROY, N. Y.

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Quality Products

Electrical Wires and Cables
for
Power and Lighting, Telephone and Telegraph, Radio and Automotive Circuits.

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Trenton, New Jersey

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MANUFACTURERS OF

Preheated Certified Malleable Iron Screw Type Anchors
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Tap Off Clamps

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4220 Clayton Avenue - - ST. LOUIS, MO.

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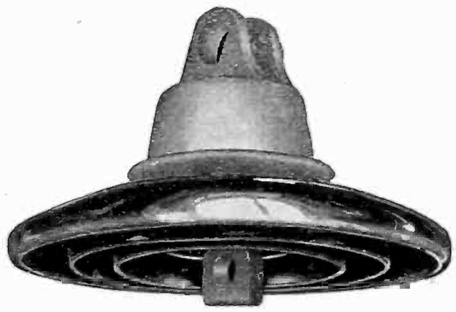

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WIRE PRODUCTS
For Varied Applications

We manufacture many types of wires, cords and cables for specific uses. Among them are:

Rubber Covered Wire—Solid Conductor, Stranded Conductor, Flexible Conductor, Extra Flexible Conductor.

Lamp Cords, Reinforced Cords, Heater Cord, Brewery Cord, Canvasite Cord, Packinghouse Cord, Deck Cable, Stage Cable, Border Light Cable, Flexible Armored Cable, Elevator Lighting Cable, Elevator Operating Cable, Elevator Annunciator Cable. Switchboard Cables, Telephone Wire, Flameproof Wires and Cables, Railway Signal Wires, High Voltage Wires and Cables. Automobile Ignition Cables, Automobile Lighting Cables, Automobile Starting Cables, Automobile Charging Cables. Moving Picture Machine Cable.

Boston Insulated Wire & Cable Co.

Main Office and Factory:
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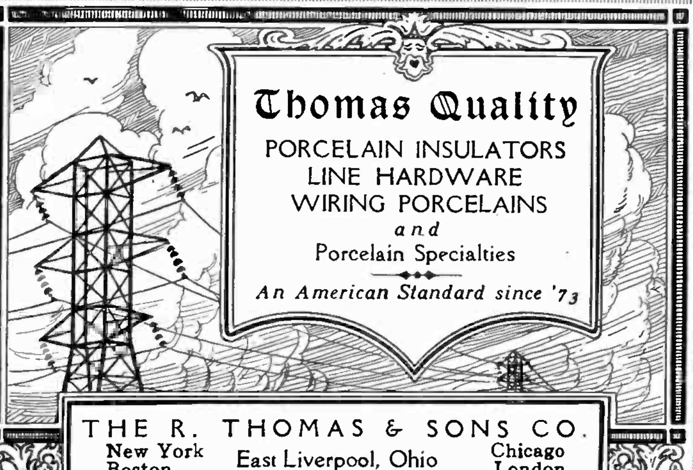
Canadian Branch, Office and Factory, Hamilton, Ont.



Thomas Quality

PORCELAIN INSULATORS
LINE HARDWARE
WIRING PORCELAINS
and
Porcelain Specialties

An American Standard since '73

THE R. THOMAS & SONS CO.
New York, Boston — East Liverpool, Ohio — Chicago, London

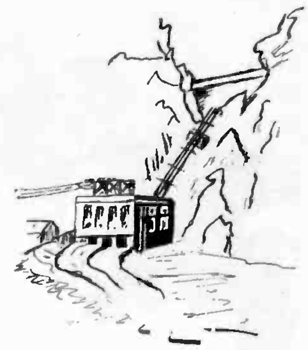
HEMINGRAY GLASS INSULATORS

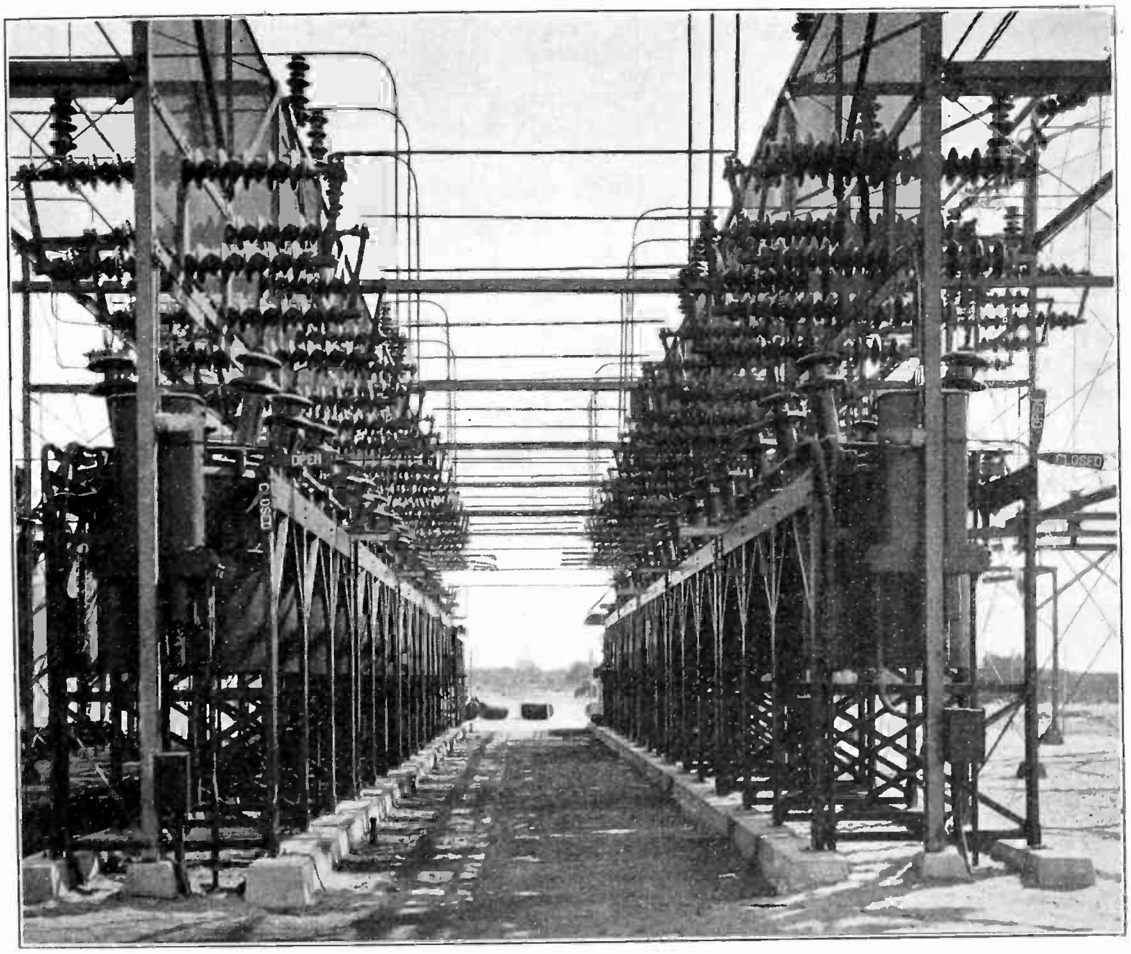
The transparency of Hemingray Glass Insulators makes line inspection very simple. The lineman can tell at a glance whether the insulator is intact or not. Hemingray insulators are mechanically and dielectrically dependable, non-porous and uniform in structure. They defy moisture and age.

Send for Bulletin No. 1.

HEMINGRAY GLASS COMPANY
Muncie, Indiana

Pacific
Six Break Oil Circuit Breakers
in
Southern California





73 Kv. Breaker Installation at Dalton Substation of Southern California Edison Company

The Success of these Breakers is Based on

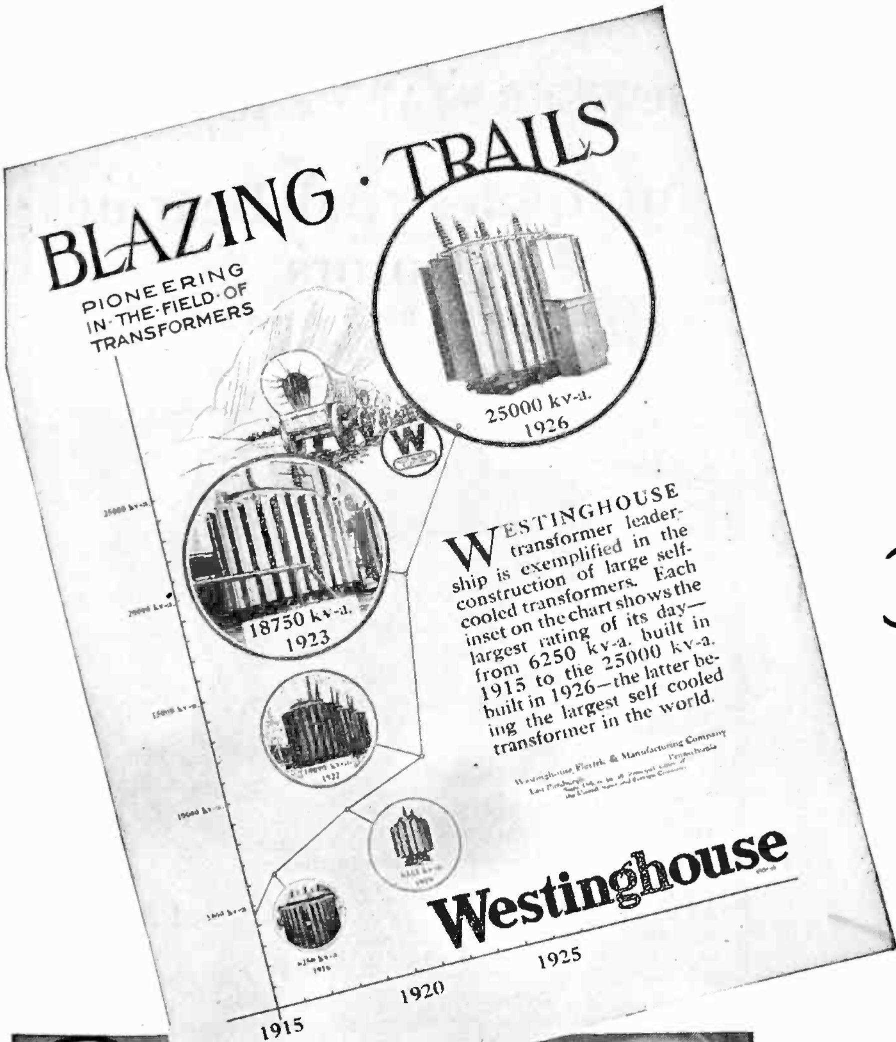
Speed!

Pacific Electric Manufacturing Co.

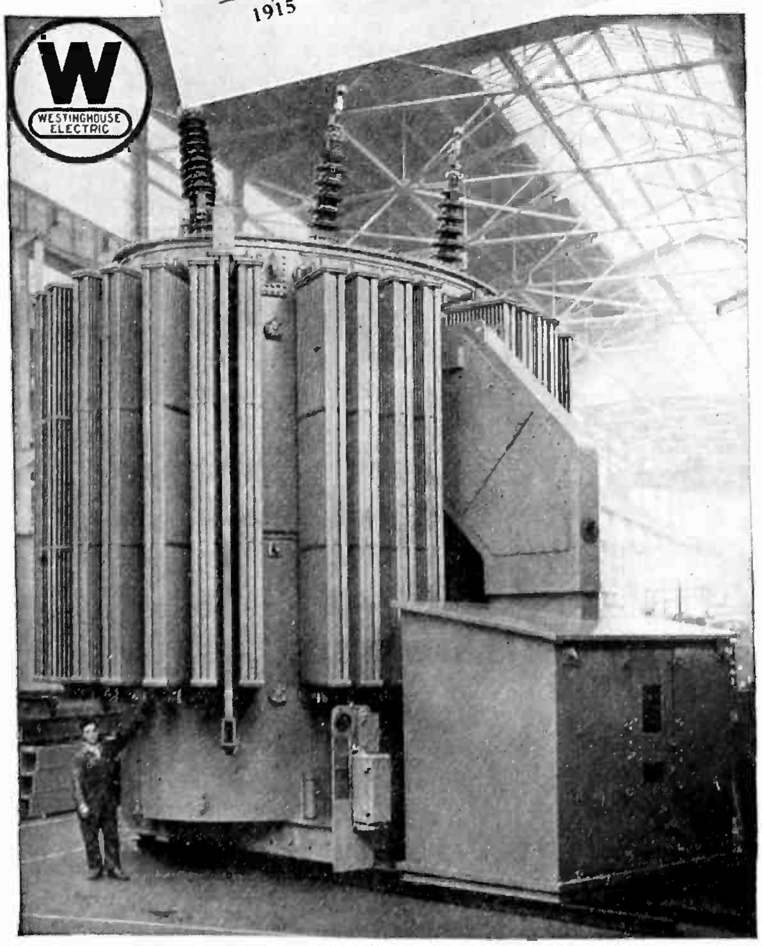
"The only Manufacturer of Horizontal Rotary Break Oil Circuit Breakers in the U. S. A."

5815 THIRD STREET, SAN FRANCISCO, CALIF.
and ST. LOUIS, MO., U. S. A.

Representatives in Principal Cities



33,333 Kv-a. for 1927



WESTINGHOUSE continues its leadership in kv-a. capacity for self-cooled transformers. Seven 33,333 kv-a. transformers are going to the Philadelphia Electric Company's Conowingo development. These are to be used in stepping down from the high-tension lines at Plymouth Meeting substation.

In addition to being the largest self-cooled transformers ever built, these transformers have other notable features. They operate at 220,000 volts—the highest commercial voltage; they have a tertiary winding of 15,000 kv-a.; they have equipment for changing taps under load.

Westinghouse engineers have again demonstrated their ability to develop unusual transformers to meet new conditions.

Westinghouse Electric & Manufacturing Company
Sharon Works Sharon, Pennsylvania
Sales Offices in All Principal Cities of the United States and Foreign Countries

Westinghouse

X90400A

There's Teamwork too - *in* Gurney Bearings

Over treacherous wasteland trails, go these harnessed huskies of the Northland. The pack may be heavy but with twelve powerful dogs teaming together, the musher drives through with strength in reserve.

The Gurney maximum type bearing applies this principal of load distribution in much the same manner. More balls of tough wear—resisting molybdenum steel team—together reducing the load on each ball with consequently greater strength in reserve and longer life.

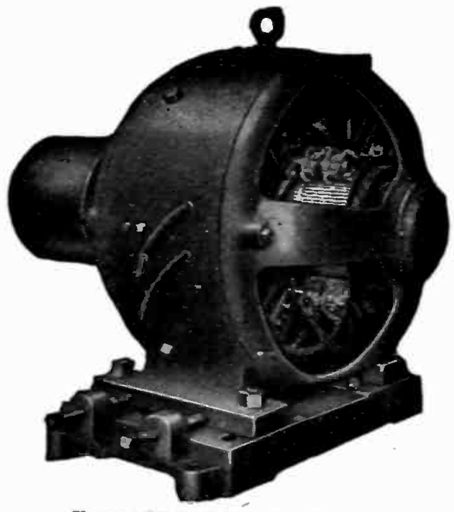
Let Gurney "team" with your product. Our Engineering Department will gladly work with you.

MARLIN-ROCKWELL CORPORATION
Gurney Ball Bearing Division
JAMESTOWN, N. Y.

GURNEY
BALL BEARINGS
BETTER STEEL · · BIG BALLS · · MORE OF THEM

THE PIONEER MANUFACTURER OF Interpole & Ball Bearing Motors

½ to 1000 H. P. D. C. and A. C.



Type "S" Ball Bearing Motor with base and pulley

ELECTRO DYNAMIC COMPANY
Established 1880
BAYONNE, N. J.
Sales Offices in Principal Cities

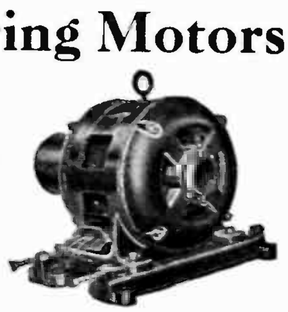
Sturtevant Electric Motors

—A. C. and D. C.; single and polyphase—built in sizes from small fractional to 250 horse-power—designed to operate under a constant full load where uninterrupted service is demanded.

B. F. STURTEVANT COMPANY
HYDE PARK, BOSTON, MASS.

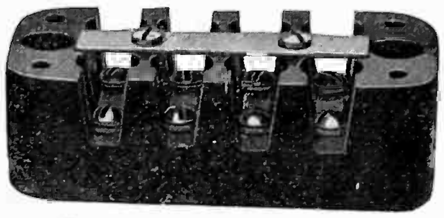
Star Ball Bearing Motors

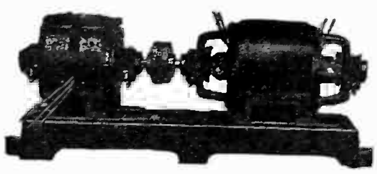
For Hard Usage — A. C. and D. C.

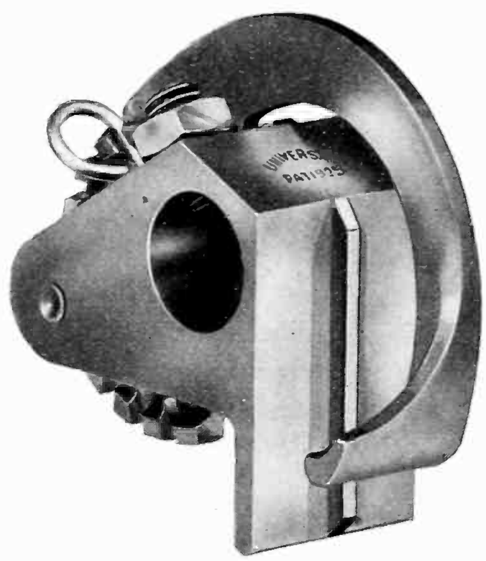


Complete line of standard motors and generators, all sizes up to 75 h. p. and 50 kw. respectively.
Our Engineering Department at your service for all special applications

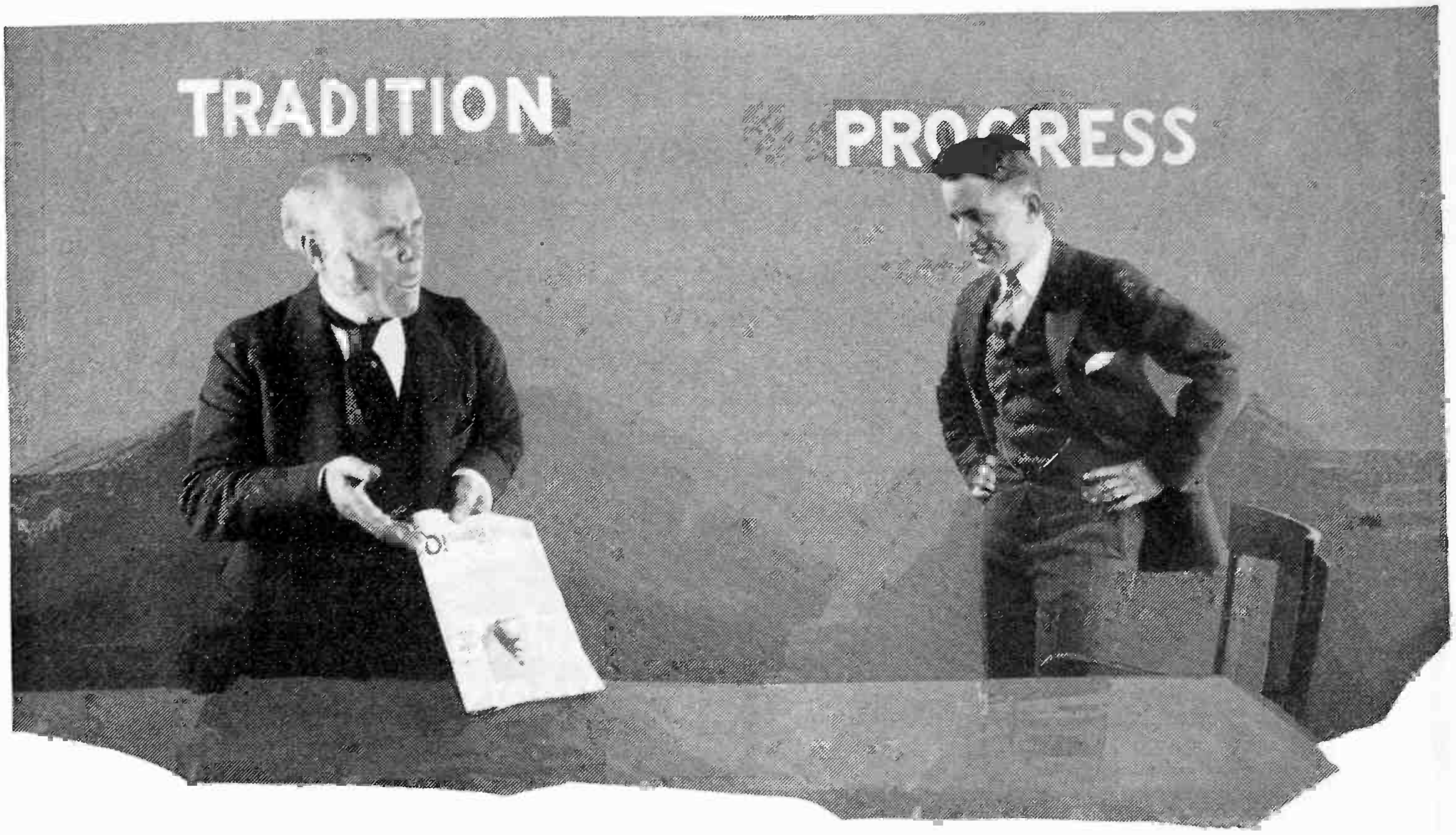
STAR ELECTRIC MOTOR CO.
NEWARK, NEW JERSEY







Lad talks in parables.



"Here, Lad—

you claim that the Lincoln people have hit on a wonderful idea in motor construction. How come that something new in a motor, one of the oldest and most thoroughly developed pieces of electrical apparatus, should so suddenly be discovered?"

"Easy, Pop—

stockings were invented in the eleventh century but they weren't discovered until the twentieth.

There have been too many cast iron petticoats on motors in the past—all following a rigid fundamentalism in design.

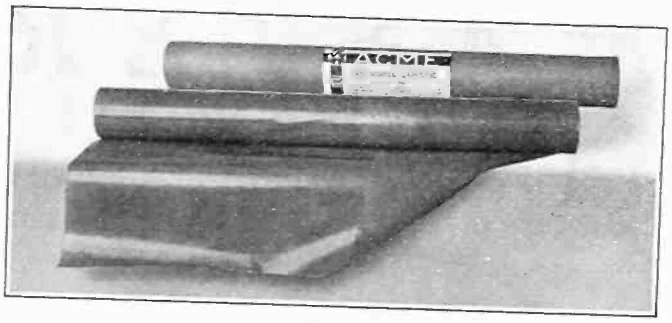
The Lincoln people in this 'Linc-Weld' motor got rid of cast iron construction—put in muscular shafts and masculine bearings to keep down bearing troubles—piled in plenty of active materials and better insulation. But they didn't make a new motor—just made it according to modern principles with a betterment of the older principles—pulled out the cast iron petticoats that warmed up the old motors—put in welded steel which let in the air.

In other words, they gave the motor a chance to step—with pep."

The Lincoln Electric Co., Dept. No. 21, Cleveland, Ohio

M-4

"Linc-Weld" LINCOLN MOTOR



We Serve only one Master—"QUALITY"!

Acme Varnished Insulations are made from long-staple cotton yarns—finest Japanese silk—or special tested papers. The varnish, made from high-grade vegetable oils, is applied under accurate heat control. The result is—extreme flexibility, wide dielectric reserve, and resistance to acid, oil, moisture and gases. The line comprises:—

Varnished Cambrics

—black and yellow, in standard 50-yard rolls, 35 to 36 inches wide, 1½-inch core tube, ends paraffined. Also in 25 or 100-yard rolls if desired. Thicknesses, from .004″ to .015″ and in other fabrics up to .030″. Standard finish, dry; optional, tacky or waxy.

Varnished Cambric Tapes

—black and yellow, cut straight or bias, sewed or seamless. 72-yard standard rolls; others to order. Widths, ½″ up. Standard core 1½″; .005″ to .015″ thicknesses. Standard finishes; yellow, dry; black, greasy. The bias tapes have 48 closely stitched seams in a standard roll.

Varnished Silks and Tapes

Color, yellow. Cut straight, 25 or 50-yard rolls untrimmed, 1½″ paper cores; cut bias. 45 deg. angle, in 50″ strips, 200 to the package. Widths, ¼″ to 36″. Dry and slightly tacky finishes .002″ to .008″ thicknesses.

Varnished Papers

—black and yellow, in standard 50-yard rolls, 36″ wide, ends paraffined. Tapes ¼″ wide and up. Thicknesses, .006″ to .020″. Dry, tacky or greasy finishes.

Varnished Tubing

Standard colors, yellow, black, red, green and brown. Standard 30″ lengths; 24″ to 36″ lengths to order. Sixteen sizes, inside diameter .042″ to .295″. Dielectric voltages from 2,500 to 5,000. (Also special tubings for voltages up to 30,000.)

Write for Catalog 3A

THE ACME WIRE CO.

Main Office and Plant, New Haven, Conn.

Branches

New York, 52 Vanderbilt Ave. Chicago, 427 West Erie Street
Cleveland, Guardian Bldg.

I-N BOARD

West Virginia

Fibre Board

For Electrical Insulation

Tested and approved by the Underwriters' Laboratories.

High tensile and dielectric strength. Used successfully by many of the large electrical manufacturers.

A decided factor for economy.

Pulp Products Department

West Virginia Pulp & Paper Company

200 Fifth Avenue, New York, N. Y.
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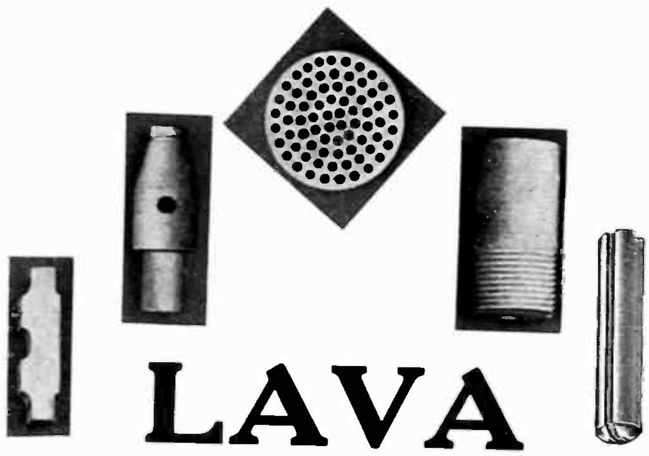
732 Sherman Street Chicago, Ill.
503 Market Street, San Francisco, Cal.

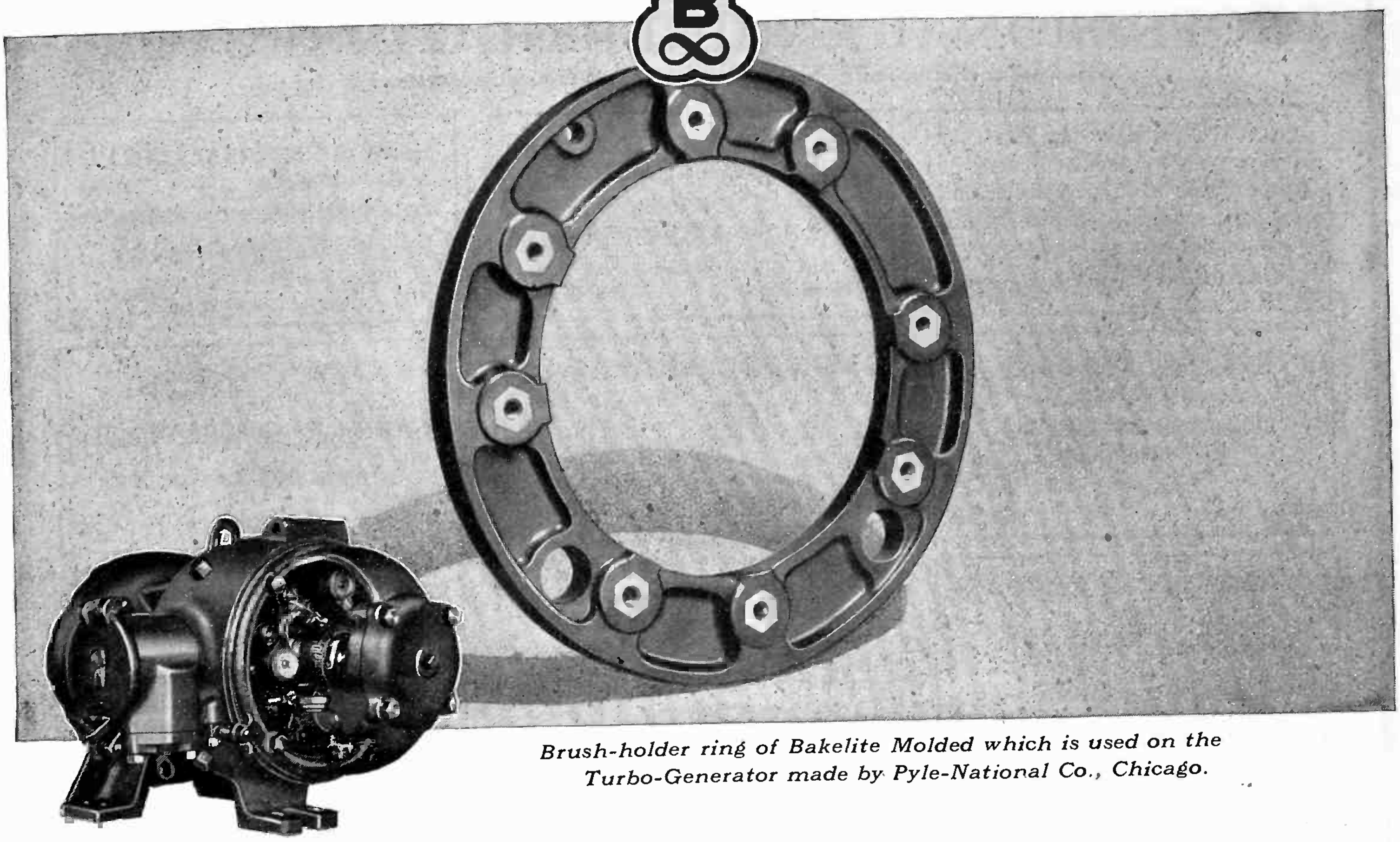


LAVA INSULATORS

Manufacturers of electrical appliances adopt lava insulators because of their dependability. Lava parts, made to special design, possess great dielectric strength.

AMERICAN LAVA CORPORATION
27-67 Williamson St.,
Chattanooga Tennessee

Manufacturers of Heat Resistant Insulators



Brush-holder ring of Bakelite Molded which is used on the Turbo-Generator made by Pyle-National Co., Chicago.

A Bakelite Molded brush-holder ring eliminated "leakage" troubles

TURBO-generators in locomotive lighting and train control service are subjected to hard usage, and every part must be exceptionally rugged and dependable. Pyle-National turbo-generators were originally provided with brush-holder rings of cast iron but these caused trouble because of leakage between brush-holder and ground.

The brush-holder ring is now made of Bakelite Molded because it provides the necessary insulation properties, eliminating leakage between holder and ground, and is also very strong. These Bakelite Molded rings are economically produced as they are formed in one operation with metal inserts firmly embedded and three operations formerly required are no longer necessary.

Bakelite Cooperation

Bakelite Sales and Service Engineers are located in important industrial centers throughout the country, and they are equipped to render prompt and helpful cooperation to present and prospective users of Bakelite Materials. The Bakelite Corporation places at their service the facilities of its extensive laboratories, and its unequalled experience in the practical application of phenol resin products to industrial needs. Write for Booklet 3 "Bakelite Molded."

BAKELITE CORPORATION
247 Park Ave., New York, N. Y., Chicago Office: 635 West 22nd St.
BAKELITE CORP. OF CANADA, LTD., 163 Dufferin St., Toronto, Ontario, Canada

BAKELITE

REGISTERED U. S. PAT. OFF.

THE MATERIAL OF A THOUSAND USES

"The registered Trade Mark and Symbol shown above may be used only on products made from materials manufactured by Bakelite Corporation. Under the capital "B" is the numerical sign for infinity, or unlimited quantity. It symbolizes the infinite number of present and future uses of Bakelite Corporation's products."

To be printed in the following issue, copy for cards must be received by the 20th of the month.

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Manufacturers and agents for machinery and supplies used in the electrical and allied industries.

Note: For reference to the Advertisements see the Alphabetical List of Advertisers on page 54.

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Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady
Western Electric Co., All Principal Cities

AIR WASHERS
Sturtevant Co., B. F., Boston

AMMETER COMPENSATING COILS
Minerallac Electric Co., Chicago

AMMETER, VOLTMETERS
(See INSTRUMENTS, ELECTRICAL)

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Matthews Corp., W. N., St. Louis

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Hubbard & Co., Pittsburgh

BATTERY CHARGING APPARATUS
Electric Specialty Co., Stamford, Conn.
Fansteel Products Co., Inc., North Chicago
General Electric Co., Schenectady
Wagner Electric Corp., St. Louis
Ward Leonard Electric Co., Mt. Vernon, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

BEARINGS, BALL
Gurney Ball Bearing Division of Marlin-Rockwell Corp., Jamestown, N. Y.
New Departure Mfg. Co., The, Bristol, Conn.
Norma-Hoffmann Bearings Corp., Stamford, Conn.
Standard Steel & Bearings, Inc., Plainville, Conn.

BEARINGS, ROLLER
Timken Roller Bearing Co., The, Canton, O.

BLOWERS
Sturtevant Co., B. F., Boston

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Kearney Corp., Jas. R., St. Louis
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., Pittsburgh

BOXES, JUNCTION
G & W Elec. Specialty Co., Chicago
Metropolitan Device Corp., Brooklyn, N. Y.
Standard Underground Cable Co., Pittsburgh

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National Carbon Co., Inc., Cleveland
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Copper Graphite
Morganite Brush Co., Inc., L. I. City, N. Y.
National Carbon Co., Inc., Cleveland
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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Ohio Brass Co., Mansfield, O.
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BUSHINGS, PORCELAIN
Ohio Brass Co., Mansfield, O.

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Dossert & Co., New York
G & W Electric Specialty Co., Chicago
General Electric Co., Schenectady
Minerallac Electric Co., Chicago
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

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Metropolitan Device Corp., Brooklyn, N. Y.

CABLES
See WIRES AND CABLES

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Kearney Corp., Jas. R., St. Louis

CLIPS, CABLE
Kearney Corp., Jas. R., St. Louis

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Sangamo Elec. Co., Springfield, Ill.

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Kearney Corp., Jas. R., St. Louis
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Belden Mfg. Co., Chicago
Dudlo Mfg. Corp., Ft. Wayne, Ind.
General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

COMMUTATOR SLOTTERS
Martindale Electric Co., The, Cleveland

COMMUTATOR STONES
Martindale Electric Co., The, Cleveland

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For Carrier Current Telephone
Wireless Specialty Apparatus Co., Boston

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General Radio Co., Cambridge, Mass.
Sangamo Elec. Co., Springfield, Ill.
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Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

CONVERTERS—SYNCHRONOUS
Allis-Chalmers Mfg. Co., Milwaukee
Electric Specialty Co., Stamford, Conn.
Wagner Electric Corp., St. Louis
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

COPPER CLAD WIRE
Belden Mfg. Co., Chicago
Copperweld Steel Co., Rankin, Pa.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

CUT-OUTS
Condit Electrical Mfg. Corp., S. Boston
General Electric Co., Schenectady
G & W Electric Specialty Co., Chicago
Kearney Corp., Jas. R., St. Louis
Metropolitan Device Corp., Brooklyn, N. Y.
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

DIMMERS, THEATRE
Ward Leonard Electric Co., Mt. Vernon, N. Y.

DRAWING INSTRUMENTS
Cramer & Co., Inc., R. W., New York

DYNAMOS
(See GENERATORS AND MOTORS)

DYNAMOTORS
Burke Electric Co., Erie, Pa.
Electric Specialty Co., Stamford, Conn.

ELECTRIFICATION SUPPLIES, STEAM ROAD
General Electric Co., Schenectady
Ohio Brass Co., Mansfield, Ohio
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

ENGINEERS, CONSULTING AND CONTRACTING
(See PROFESSIONAL ENGINEERING DIRECTORY)

ENGINES
Gas & Gasoline
Allis-Chalmers Mfg. Co., Milwaukee
Sturtevant Company, B. F., Boston
Oil
Allis-Chalmers Mfg. Co., Milwaukee
Sturtevant Company, B. F., Boston
Steam
Allis-Chalmers Mfg. Co., Milwaukee
Sturtevant Company, B. F., Boston

FANS, MOTOR
Century Electric Co., St. Louis
General Electric Co., Schenectady
Star Electric Motor Co., Newark, N. J.
Sturtevant Company, B. F., Boston
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

FARM LIGHTING GENERATORS
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

FIBRE
Belden Mfg. Co., Chicago
National Vulcanized Fibre Co., Wilmington, Del.

FLOW METERS
General Electric Co., Schenectady

FURNACES, ELECTRIC
General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

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FUSES

Enclosed Refillable

General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Enclosed Non-Refillable

General Electric Co., Schenectady
Western Electric Co., All Principal Cities

Open Link

General Electric Co., Schenectady
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities

High Tension

Delta-Star Electric Co., Chicago
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities

FUSE PULLERS

Kearney Corp., Jas. R., St. Louis

GEARS, FIBRE

General Electric Co., Schenectady

GENERATORS AND MOTORS

Allis-Chalmers Mfg. Co., Milwaukee
Burke Electric Co., Erie, Pa.
Century Electric Co., St. Louis
Chandeysson Electric Co., St. Louis
Electric Specialty Co., Stamford, Conn.
Electro-Dynamic Co., Bayonne, N. J.
General Electric Co., Schenectady
Lincoln Electric Co., The, Cleveland
Star Electric Motor Co., Newark, N. J.
Sturtevant Company, B. F., Boston
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

GENERATING STATION EQUIPMENT

Allis-Chalmers Mfg. Co., Milwaukee
Burke Electric Co., Erie, Pa.
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

GROUND RODS

Copperweld Steel Co., Rankin, Pa.
Western Electric Co., All Principal Cities

HARDWARE, POLE LINE AND INSULATOR

Ohio Brass Co., Mansfield, O.

HEADLIGHTS

Ohio Brass Co., Mansfield, O.

HEATERS, INDUSTRIAL

General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

IGNITION SYSTEMS, AUTOMOBILE

Wagner Electric Corp., St. Louis

INDICATORS, SPEED

Bristol Co., The, Waterbury, Conn.
Roller-Smith Co., New York

INDICATORS, REMOTE, WATER LEVEL

Bristol Co., The, Waterbury, Conn.
Cramer & Co., Inc., R. W., New York

INSTRUMENTS, ELECTRICAL

Graphic

Bristol Co., The. Waterbury, Conn.
Ferranti, Ltd., Hollinwood, England
Ferranti, Inc., New York
Ferranti Electric, Ltd., Toronto, Ont.
General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Indicating

Bristol Co., The, Waterbury, Conn.
Burt, Dr. Robert C, Pasadena
Ferranti Ltd., Hollinwood, England
Ferranti, Inc., New York
Ferranti Electric, Ltd., Toronto, Ont.
General Electric Co., Schenectady
Jewell Elec. Instrument Co., Chicago
Roller-Smith Co., New York
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Weston Elec. Inst. Corp., Newark, N. J.

Integrating

Duncan Elec. Mfg. Co., Lafayette, Ind.
Ferranti, Ltd., Hollinwood, England
Ferranti, Inc., New York
Ferranti Electric, Ltd., Toronto, Ont.
General Electric Co., Schenectady
Roller-Smith Co., New York
Sangamo Elec. Co., Springfield, Ill.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Radio

General Radio Co., Cambridge, Mass.
Jewell Elec. Instrument Co., Chicago

Repairing and Testing

Electrical Testing Laboratories, New York
Jewell Elec. Instrument Co., Chicago

Scientific, Laboratory, Testing

Burt, Dr. Robert C., Pasadena
General Electric Co., Schenectady
Jewell Elec. Instrument Co., Chicago
Metropolitan Device Corp., Brooklyn, N. Y.
Roller-Smith Co., New York
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh
Weston Elec. Inst. Corp., Newark, N. J.

Telegraph

Western Electric Co., All Principal Cities

INSULATING MATERIALS

Board

General Electric Co., Bridgeport, Conn.
West Va. Pulp & Paper Co., New York

Cloth

Acme Wire Co., New Haven, Conn.
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Mineralac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Composition

American Lava Corp., Chattanooga
Bakelite Corporation, New York
Belden Mfg. Co., Chicago
General Electric Co., Bridgeport, Conn.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Compounds

General Electric Co., Bridgeport, Conn.
Mineralac Electric Co., Chicago
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Fibre

General Electric Co., Bridgeport, Conn.
National Vulcanized Fibre Co., Wilmington, Del.
West Va. Pulp & Paper Co., New York

Lava

American Lava Corp., Chattanooga, Tenn.

Mica

Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Paper

Acme Wire Co., New Haven, Conn.
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Silk

Acme Wire Co., New Haven, Conn.
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.

Tape

Belden Mfg. Co., Chicago
General Electric Co., Bridgeport, Conn.
Mineralac Electric Co., Chicago
Okonite Co., The, Passaic, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Varnishes

Acme Wire Co., New Haven, Conn.
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Mineralac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

INSULATORS, HIGH TENSION

Composition

General Electric Co., Schenectady

Glass

Hemingray Glass Co., Muncie, Ind.

High Voltage Glass

Corning Glass Works, "PYREX," Corning, N. Y.

Porcelain

Canadian Porcelain Co., Ltd., Hamilton, Ont.
General Electric Co., Schenectady
Lapp Insulator Co., Inc., LeRoy, N. Y.
Locke Insulator Corp., Baltimore
Ohio Brass Co., Mansfield, O.
Thomas & Sons Co., R., East Liverpool, O.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Post Type

Delta-Star Electric Co., Chicago
Ohio Brass Co., Mansfield, O.

INSULATORS, TELEPHONE & TELEGRAPH

Hemingray Glass Co., Muncie, Ind.
Ohio Brass Co., Mansfield, O.
Western Electric Co., All Principal Cities

INSULATOR PINS

Hubbard & Co., Pittsburgh
Ohio Brass Co., Mansfield, O.
Thomas & Sons Co., R., East Liverpool, O.

LAMP GUARDS

Matthews Corp., W. N., St. Louis
Western Electric Co., All Principal Cities

LAVA

American Lava Corp., Chattanooga

LIGHTNING ARRESTERS

Delta-Star Electric Co., Chicago
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

LOCOMOTIVES, ELECTRIC

General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

LUBRICANTS

Texas Co., The, New York

MAGNETIC SEPARATORS

Electric Controller & Mfg. Co., Cleveland

METERS, ELECTRICAL

(See INSTRUMENTS ELECTRICAL)

METER SEALS

Metropolitan Device Corp., Brooklyn, N. Y.

MICA PRODUCTS

Westinghouse Elec. & Mfg. Co., E. Pittsburgh

MICA UNDERCUTTERS

Martindale Electric Co., The, Cleveland

MOLDED INSULATION

Bakelite Corporation, New York
Belden Mfg. Co., Chicago
Burke Electric Co., Erie, Pa.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

MOLYBDENUM

Fansteel Products Co., Inc., North Chicago

MOTORS

(See GENERATORS AND MOTORS)

OHMMETERS

Jewell Elec. Instrument Co., Chicago
Martindale Electric Co., Cleveland
Roller-Smith Co., New York
Weston Elec. Instr. Corp., Newark, N. J.

OIL SEPARATORS & PURIFIERS

Sharples Specialty Co., The, Philadelphia
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

OSCILLOSCOPES

Burt, Dr. Robert C., Pasadena

PANEL BOARDS

(See SWITCHBOARDS)

PATENT ATTORNEYS

(See PROFESSIONAL ENGINEERING DIRECTORY)

PHOTO-ELECTRIC CELLS

Burt, Dr. Robert C., Pasadena

PLUGS

Delta-Star Electric Co., Chicago
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

POLES, STEEL

American Bridge Co., Pittsburgh
Western Electric Co., All Principal Cities

POLES—TIES, WOOD

Western Electric Co., All Principal Cities

POTHEADS

G & W Electric Specialty Co., Chicago
Ohio Brass Co., Mansfield, O.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

PROTECTIVE DEVICES

Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities

PULLERS, SLACK

Matthews Corp., W. N., St. Louis

PUMPS

Allis-Chalmers Mfg. Co., Milwaukee

RADIO LABORATORY APPARATUS

General Radio Co., Cambridge, Mass.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RAILWAY SUPPLIES, ELECTRIC

General Electric Co., Schenectady
Ohio Brass Co., Mansfield, O.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

REACTORS

General Electric Co., Schenectady
Metropolitan Device Corp., Brooklyn, N. Y.

RECTIFIERS

Fansteel Products Co., Inc., North Chicago
General Electric Co., Schenectady
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

REELS, PAYOUT AND TAKEUP

Matthews Corp., W. N., St. Louis

REGULATORS, VOLTAGE

Burke Electric Co., Erie, Pa.
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RELAYS

Cramer & Co., Inc., R. W., New York
Electric Controller & Mfg. Co., Cleveland
General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

RESISTOR UNITS

General Electric Co., Schenectady
Ward Leonard Electric Co., Mt. Vernon, N. Y.

RHEOSTATS

General Electric Co., Schenectady
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt. Vernon, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

ROPE, WIRE

American Steel & Wire Co., Chicago
Roebling's Sons Co., John A., Trenton, N. J.

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General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SHEETS, ELECTRICAL
Trumbull Steel Co., The, Warren, O.

SLEEVE TWISTERS
Kearney Corp., Jas. R., St. Louis

SOCKETS AND RECEPTACLES
General Electric Co., Schenectady
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SOLENOIDS
Acme Wire Co., New Haven, Conn.
Belden Mfg. Co., Chicago
Dudlo Mfg. Co., Ft. Wayne, Ind.
Electric Controller & Mfg. Co., Cleveland
General Electric Co., Schenectady
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt. Vernon, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SPRINGS
American Steel & Wire Co., Chicago

STARTERS, MOTOR
Condit Electrical Mfg. Corp., Boston
Electric Controller & Mfg. Co., Cleveland
General Electric Co., Schenectady
Rowan Controller Co., Baltimore, Md.
Sundh Electric Co., Newark, N. J.
Ward Leonard Electric Co., Mt. Vernon, N. Y.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

STARTING AND LIGHTING SYSTEMS, AUTOMOBILE
Wagner Electric Corp., St. Louis

STEEL, SHEET & STRIPS
Trumbull Steel Co., The, Warren, O.

STOKERS, MECHANICAL
Sturtevant Company, B. F., Boston
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SUB-STATIONS
General Electric Co., Schenectady
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SWITCHBOARDS
Allis-Chalmers Mfg. Co., Milwaukee
Condit Electrical Mfg. Corp., Boston
General Electric Co., Schenectady
Metropolitan Device Corp., Brooklyn, N. Y.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

SWITCHES

Automatic Time
Cramer & Co., Inc., R. W., New York
General Electric Co., Schenectady
Minerallac Electric Co., Chicago
Sundh Electric Co., Newark, N. J.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Disconnecting
Burke Electric Co., Erie, Pa.
Condit Electrical Mfg. Corp., Boston
Delta-Star Electric Co., Chicago
General Electric Co., Schenectady
Kearney Corp., Jas. R., St. Louis
K-P-F Electric Co., San Francisco
Matthews Corp., W. N., St. Louis
Pacific Elec. Mfg. Co., San Francisco
Thoner & Martens, Boston

Fuse
General Electric Co., Schenectady
Kearney Corp., Jas. R., St. Louis
Matthews Corp., W. N., St. Louis
Metropolitan Device Corp., Brooklyn, N. Y.
Thoner & Martens, Boston

Knife
Condit Electrical Mfg. Corp., Boston
Cramer & Co., Inc., R. W., New York
Electric Controller & Mfg. Co., Cleveland
General Electric Co., Schenectady
Matthews Corp., W. N., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Magnetic
Ward Leonard Electric Co., Mt. Vernon, N. Y.

Oil
Condit Electrical Mfg. Corp., Boston
General Electric Co., Schenectady
Pacific Elec. Mfg., Co., San Francisco
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Remote Control
Condit Electrical Mfg. Corp., Boston
Cramer & Co., Inc., R. W., New York
General Electric Co., Schenectady
Rowan Controller Co., Baltimore
Sangamo Elec. Co., Springfield, Ill.
Sundh Electric Co., Newark, N. J.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TANTALUM
Fansteel Products Co., Inc., North Chicago

TELEGRAPH APPARATUS
Western Electric Co., All Principal Cities

TELEPHONE CONNECTORS
Kearney Corp., Jas. R., St. Louis

TELEPHONE EQUIPMENT
Western Electric Co., All Principal Cities

TESTING LABORATORIES
Electrical Testing Labs., New York

TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh
Western Electric Co., All Principal Cities

TRANSFORMERS
Allis-Chalmers Mfg. Co., Milwaukee
American Transformer Co., Newark, N. J.
Duncan Elec. Mfg. Co., Lafayette, Ind.
Ferranti, Ltd., Hollinwood, England
Ferranti, Inc., New York
Ferranti Electric, Ltd., Toronto, Ont.
General Electric Co., Schenectady
Jefferson Elec. Mfg. Co., Chicago
Kuhlman Electric Co., Bay City, Mich.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Sangamo Elec. Co., Springfield, Ill.
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

Factory
American Transformer Co., Newark, N. J.
Kuhlman Electric Co., Bay City, Mich.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh
Wagner Electric Corp., St. Louis
Western Electric Co., All Principal Cities

Furnace
Allis-Chalmers Mfg. Co., Milwaukee
American Transformer Co., Newark, N. J.
Moloney Electric Co., St. Louis
Pittsburgh Transformer Co., Pittsburgh

Metering
American Transformer Co., Newark, N. J.
Ferranti, Ltd., Hollinwood, England
Ferranti, Inc., New York
Ferranti Electric, Ltd., Toronto, Ont.
Pittsburgh Transformer Co., Pittsburgh
Sangamo Elec. Co., Springfield, Ill.

Mill Type
Pittsburgh Transformer Co., Pittsburgh

Radio
American Transformer Co., Newark, N. J.
Ferranti, Ltd., Hollinwood, England
Ferranti, Inc., New York
Ferranti Electric, Ltd., Toronto, Ont.
Jefferson Elec. Mfg. Co., Chicago

Street Lighting
Kuhlman Electric Co., Bay City, Mich.
Western Electric Co., All Principal Cities

TROLLEY LINE MATERIALS
General Electric Co., Schenectady
Ohio Brass Co., Mansfield, O.
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TURBINES, HYDRAULIC
Allis-Chalmers Mfg. Co., Milwaukee

TURBINES, STEAM
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady
Sturtevant Company, B. F., Boston
Western Electric Co., All Principal Cities
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

TURBO-GENERATORS
Allis-Chalmers Mfg. Co., Milwaukee
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

VALVES, BRASS

Gas, Water, Steam
Ohio Brass Co., Mansfield, O.

VALVE CONTROL, ELECTRIC
Bristol Company, The, Waterbury, Conn.

VARNISHES, INSULATING
General Electric Co., Bridgeport, Conn.
Irvington Varnish & Ins. Co., Irvington, N. J.
Minerallac Electric Co., Chicago
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

WELDING MACHINES, ELECTRIC
General Electric Co., Schenectady
Lincoln Electric Co., The, Cleveland
Ohio Brass Co., Mansfield, O.
Westinghouse Elec. & Mfg. Co., E. Pittsburgh

WELDING WIRES & RODS
American Steel & Wire Co., Chicago
Lincoln Electric Co., Cleveland
Ohio Brass Co., Mansfield, O.

WIRES AND CABLES

Armored Cable
American Steel & Wire Co., Chicago
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady
Habirshaw Cable & Wire Corp., New York
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

WIRES AND CABLES—*Continued.*

Asbestos Covered
American Steel & Wire Co., Chicago
Belden Mfg. Co., Chicago
General Electric Co., Schenectady

Automotive
American Steel & Wire Co., Chicago
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady
Habirshaw Cable & Wire Corp., New York
Kerite Ins. Wire & Cable Co., New York
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Bare Copper
American Steel & Wire Co., Chicago
Anaconda Copper Mining Co., Chicago
Belden Mfg. Co., Chicago
Copperweld Steel Co., Rankin, Pa.
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Copper Clad
Copperweld Steel Co., Rankin, Pa.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Flexible Cord
American Steel & Wire Co., Chicago
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Heavy Duty Cord
American Steel & Wire Co., Chicago
Belden Mfg. Co., Chicago
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Okonite Company, The, Passaic, N. J.
Simplex Wire & Cable Co., Boston

Fuse
American Steel & Wire Co., Chicago
General Electric Co., Schenectady
Roebling's Sons Co., John A., Trenton, N. J.
Western Electric Co., All Principal Cities

Lead Covered (Paper and Varnished cambric insulated)
American Steel & Wire Co., Chicago
Anaconda Copper Mining Co., Chicago
General Electric Co., Schenectady
Habirshaw Cable & Wire Corp., New York
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., The, Inc., Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Magnet
American Steel & Wire Co., Chicago
Belden Mfg. Co., Chicago
Dudlo Mfg. Corp., Fort Wayne, Ind.
General Electric Co., Schenectady
Maring Wire Co., Muskegon, Mich.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

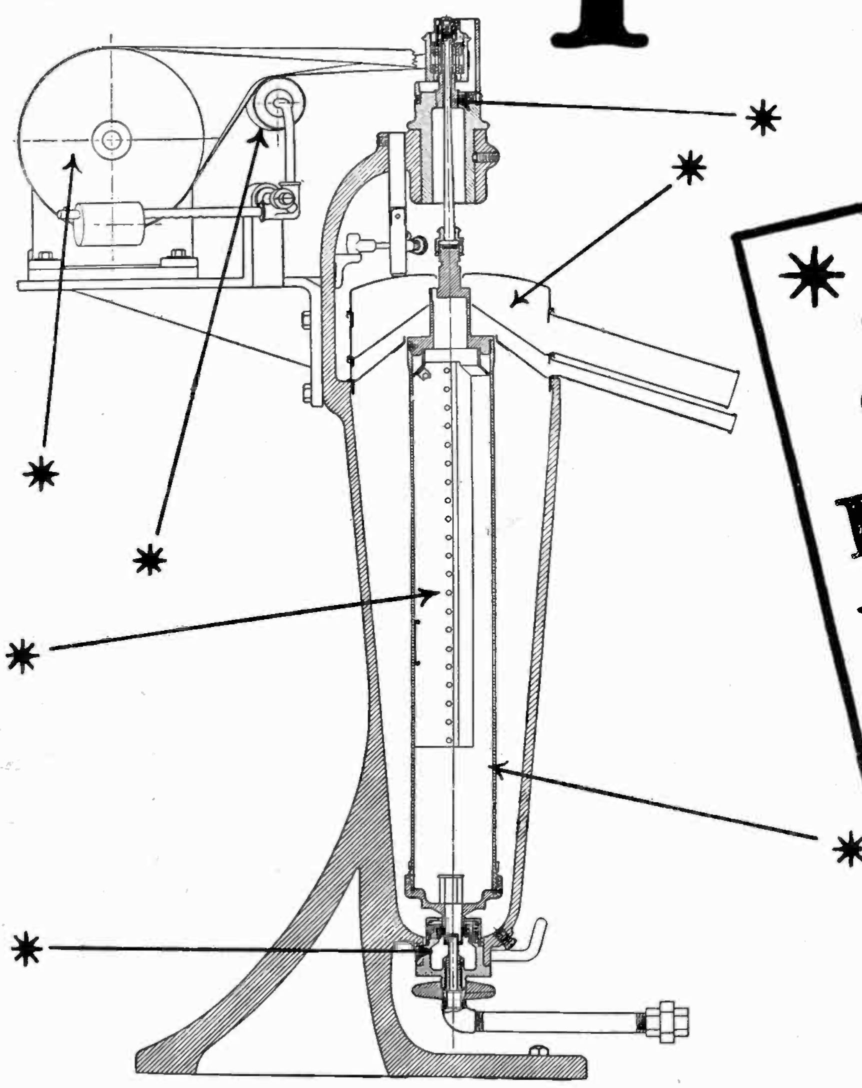
Rubber Insulated
American Steel & Wire Co., Chicago
Belden Mfg. Co., Chicago
Boston Ins. Wire & Cable Co., Boston
General Electric Co., Schenectady
Habirshaw Cable & Wire Corp., New York
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Tree Wire
Hazard Manufacturing Co., Wilkes-Barre, Pa.
Okonite Company, The, Passaic, N. J.
Simplex Wire & Cable Co., Boston

Trolley
American Steel & Wire Co., Chicago
Anaconda Copper Mining Co., Chicago
Copperweld Steel Co., Rankin, Pa.
Roebling's Sons Co., John A., Trenton, N. J.
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

Weatherproof
American Steel & Wire Co., Chicago
Anaconda Copper Mining Co., Chicago
Copperweld Steel Co., Rankin, Pa.
General Electric Co., Schenectady
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Roebling's Sons Co., John A., Trenton, N. J.
Simplex Wire & Cable Co., Boston
Standard Underground Cable Co., Pittsburgh
Western Electric Co., All Principal Cities

SHARPLES Simplicity



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With the Sharples there are no long shut-downs for repairs—no difficulty in cleaning—no inaccessibility to working parts. Any man of ordinary skill can assemble and operate the machine with ease.

The Sharples Portable Transformer Oil Purifier is the handiest outfit available for cleaning dirty insulating oils. It makes it easy to bring oil back to a dielectric strength of 22,000 volts or better, quickly and at low cost. Complete Bulletin mailed on request.

See the Sharples display at Booth 92, New York Power Show, December 5th to 10th

THE SHARPLES SPECIALTY COMPANY, 2324 WESTMORELAND STREET, PHILADELPHIA Boston, New York, Pittsburgh, Chicago, Detroit, Tulsa, New Orleans, San Francisco, Los Angeles, Seattle, Toronto, London, Paris, Tokio.

SHARPLES

A GREAT FORCE

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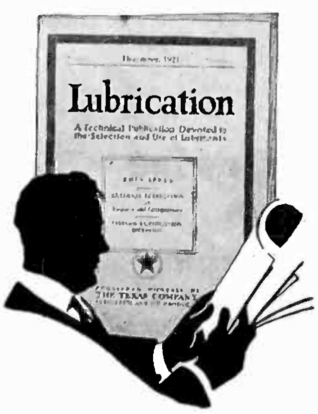

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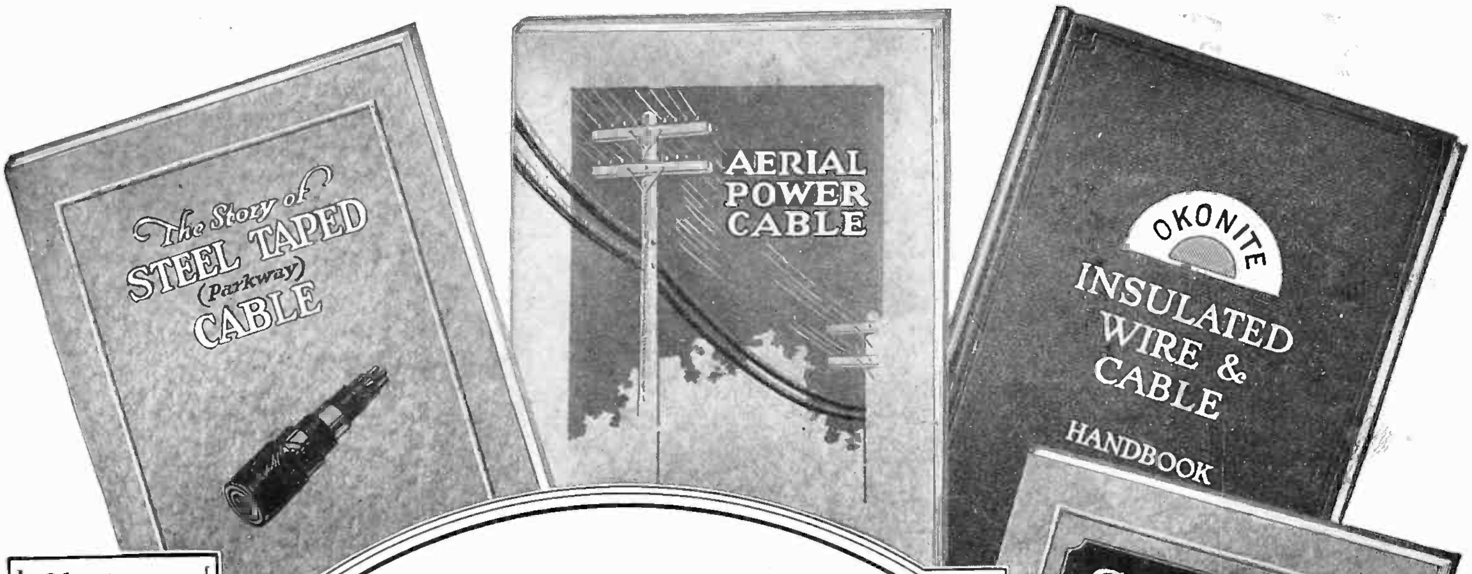

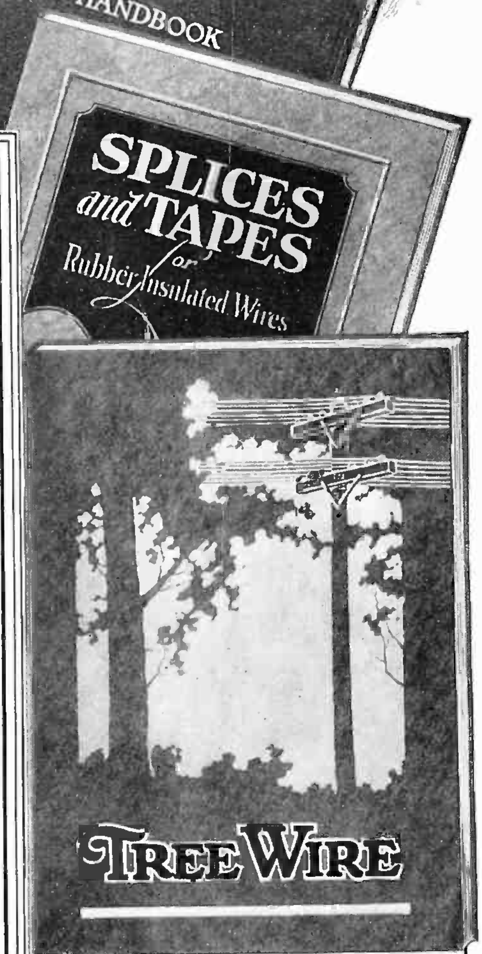

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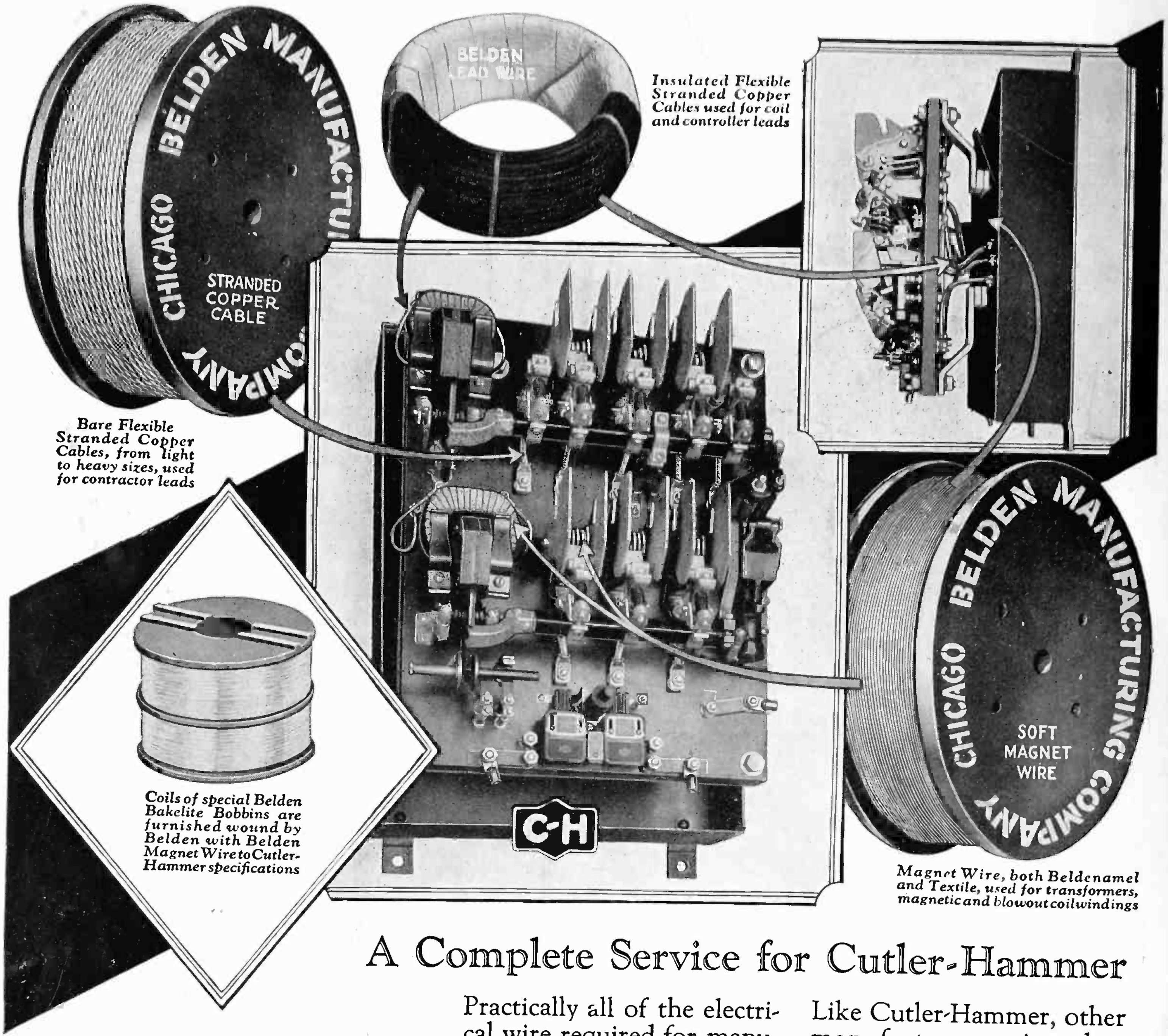

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