GENERAL ELECTRIC REVIEW

INDEX TO VOLUME XXVI

January, 1923—December, 1923

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE   Editor, JOHN R. HEWETT   Associate Editor, E. C. SANDERS

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Lighting developments during the year 1922 are described in the article beginning on page 7

GENERAL ELECTRIC
REVIEW

THE ENGINEER AND CHRISTMAS

As our January issue comes off the press just at Christmas time we should like, in this number, to wish all our friends a very Happy Christmas and a Prosperous New Year.

We are fortunate in being able to announce the establishment of the Charles A. Coffin Foundation at this time as there is a good deal of the Christmas spirit in the intent of the awards that will be made each year from this fund.

How many Christmas presents of the best and most useful kind has the electrical industry made to mankind during the marvelous age in which Mr. Coffin has been the leading spirit in this leading industry! Since electricity has been used as the driving force of industry we have made more material progress each decade than we made in a century before. And the pace quickens rather than slackens!

Still we talk of the good old times with regret and sometimes shake our heads in doubt as to where our modern notions of progress are to carry us.

Think—would either the millionaire or the laborer go back to live as his grandfather lived? The laborer has many comforts and luxuries today that the millionaire could not procure with all his wealth a few decades ago, because they did not exist.

Science is a fairy godmother to mankind.

The more immature man may, like Tiny Tim, call out "God bless every one" and leave it at that—we like the sentiment. But the engineer and the scientist must call out "God *has* blessed every one but they must labor to reap the harvest that He has sown."

All possible blessings are on the earth and have been for many long centuries. The bottled sunshine and the many brilliant colors that make our Christmas greeting attractive were latent blessings long before man discovered them and learned the processes that make them useful and bring them to our homes. All the materials for our trains, ships, motor cars, flying machines, telephones, telegraphs, wireless, etc., etc. and the energy for working them lay hidden for untold centuries. It was not just shouting out "God bless every one" that turned these latent blessings into actual blessings—it was work.

Perhaps the greatest blessing of all is the privilege of doing this useful work and the knowledge that opportunities to do useful work increase rather than decrease with each new invention and discovery.

The blessings to be unfolded in the future are greater than those as yet revealed by work and we are proud in the belief that our industry—the electrical industry—is to be the medium through which many of these blessings are to be secured for mankind in the future.

OPPORTUNITY

With doubt and dismay you are smitten,
  You think there's no chance for you, son?
Why, the best books haven't been written,
  The best race hasn't been run,
The best score hasn't been made yet,
  The best song hasn't been sung,
The best tune hasn't been played yet;
  Cheer up, for the world is young!

No chance? Why, the world is just eager
  For things that you ought to create;
Its store of true wealth is still meagre,
  Its needs are incessant and great;
It yearns for more power and beauty,
  More laughter and love and romance,
More loyalty, labor and duty,
  No chance—why, there's nothing but chance!

For the best verse hasn't been rhymed yet,
  The best house hasn't been planned,
The highest peak hasn't been climbed yet,
  The mightiest rivers aren't spanned;
Don't worry and fret, faint-hearted,
  The chances have just begun,
For the Best jobs haven't been started,
  The Best work hasn't been done.

—*Berton Braley.*

J. R. H.

THE COFFIN FOUNDATION

(**An Editorial from the *New York Herald*, December 5, 1922**)

The General Electric Company has established a fund of $400,000, to be known as the Charles A. Coffin Foundation, the income from which is to be devoted to encouraging the study and the application of the science of electricity. The General Electric Company thus pays public and enduring tribute to the man who was its president from its organization until 1913 and chairman of its board from 1913 until this year—to Charles A. Coffin, business man and financier, to whom the electrical industry in the United States owes much of its rapid and sound development.

Mr. Coffin is a Maine man, endowed with the quality of common sense so conspicuously possessed by the leaders of thought and action the Pine Tree State has given to the nation, and gifted with breadth of vision that enables him to visualize business as something more than an opportunity to pay fair wages to workers and to earn fair profits for stockholders. The history of the General Electric Company is the history of Charles A. Coffin, and the history of Charles A. Coffin is one of constant striving to improve on the best that has yet been done.

The Research Laboratory of the General Electric Company at Schenectady, with the distinguished scientist Dr. Willis R. Whitney at the head of its numerous staff of investigators, is one of the concrete examples of the practical application of Mr. Coffin's ambition to put American industry in the forefront. In this great institution Mr. Coffin has used for the advancement of science all the resources of the great corporation he has built up. The fruits of its expensive and patient inquiries have been made available to the public; no selfish purpose has animated its administration. The record of its contribution to the cause of the nation in the war has never been told. When it is, another inspiring chapter of devoted patriotism will be written.

The policy and the practices of the corporation which Mr. Coffin has directed as it forged its way to world-wide importance were the natural expressions of his keen intelligence, his wide sympathy and his ambition to achieve that success which those attain who raise the standard of mankind's comfort, safety and happiness by enlarging man's opportunity to do for himself. Mr. Coffin opened new fields of employment, gave new rewards to manual skill and intellectual capacity, offered new incentive to men and women to spend their talents in bettering the world they live in. It is in keeping with this that his monument should be a permanent foundation which will afford in the years to come recognition and encouragement to other toilers in the calling in which Mr. Coffin's genius has been displayed.

The circumstance that Mr. Coffin's associates have conferred this honor while he may personally influence the course of its development, should he be so inclined, gives added testimony to the respect and confidence those who know him most intimately repose in him.

Charles A. Coffin Foundation

On May 16, 1922, Mr. Charles A. Coffin in his 78th year retired from the active leadership of the General Electric Company.

Mr. Coffin has been identified with the development of the electrical industry since 1882. He was the founder and creator of the General Electric Company of which he has been the inspiration and leader for thirty years.

As an expression of appreciation of Mr. Coffin's great work not only for the General Electric Company but also for the entire electrical industry and with the desire to make this appreciation enduring and constructive, as Mr. Coffin's life and work have been, the Board of Directors of the General Electric Company created on his retirement and now desire to announce the "Charles A. Coffin Foundation."

GERARD SWOPE, President.

By action of its Board of Directors, the General Electric Company has set aside a fund of $400,000, to be known as the "CHARLES A. COFFIN FOUNDATION," the income from which, amounting to approximately $20,000 per year, will be available for encouraging and rewarding service in the electrical field by giving prizes to its employees, recognition to lighting, power and railway companies for improvement in service to the public and fellowships to graduate students and funds for research work at technical schools and colleges.

The foundation will be controlled and administered by a Foundation Committee appointed by the Board. This Committee, within the limits of the purposes for which the foundation is created, will have power to change the conditions applicable to the distribution of the fund and the amounts for each particular purpose.

The Committee proposes to distribute the income of the foundation as follows:

First. Eleven thousand dollars in prizes for the most signal contributions by employees of the General Electric Company toward the increase of its efficiency or progress in the electrical art. Particularly, the prizes are to further encourage suggestions from workmen. With each prize, the Company will give a certificate of award.

Foremen's prizes are to be awarded for the best department, taking into account its appearance, efficiency of operation, and conditions which add to the better conduct of the work and the welfare of the employees.

All employees of the Company, except Executive Officers, Heads of Departments, Works Managers, Superintendents, District Office Managers and similar executives, are eligible for such prizes.

In works where Employees' Representation has been adopted, such representatives will cooperate with the Prize Committee in awarding prizes in such works.

Second. A gold medal, to be known as the "Charles A. Coffin Medal," will be awarded annually to the Public Utility Operating Company within the United States which, during the year, has made the greatest contribution towards increasing the advantages of the use of electric light and power for the convenience and well-being of the public and the benefit of the industry. The Company receiving the medal will also receive one thousand dollars for its Employees' Benefit or similar fund.

A Committee to be named by the National Electric Light Association and known as the "Charles A. Coffin Prize Committee of the National Electric Light Association," which shall consist of its President, Chairman of its Public Policy Committee and a third member nominated by them, will award this medal, acting with the advice and cooperation of a Committee appointed by the Foundation Committee. The expenses of the Committee are to be paid out of the income of the foundation.

Third. A gold medal, to be known as the "Charles A. Coffin Medal," will be awarded annually to the Electric Railway Company within the United States which, during the year, has made the greatest contribution towards increasing the advantages of electric transportation for the convenience and well-being of the public and the benefit of the industry. The Company receiving the medal will also receive one thousand dollars for its Employees' Benefit or similar fund.

A Committee, to be named by the American Electric Railway Association and known as the "Charles A. Coffin Prize Committee of the American Railway Association," which shall consist of its President, the Chairman of the Committee on Policy, and a third member nominated by them, will award this medal acting with the advice and cooperation of a committee appointed by the Foundation Committee. The expenses of the Committee are to be paid out of the income of the foundation.

Fourth. Five thousand dollars is to be awarded annually for fellowships to graduates of American colleges and technical schools who, by the character of their work, and on the recommendation of the faculty of the institution where they have studied, could with advantage continue their research work either here or abroad; or some portion or all of the fund may be used to further the research work at any of the colleges or technical schools in the United States. The fields in which these fellowships and funds for research work are to be awarded are:

Electricity
Physics
Physical Chemistry.

A Committee appointed by the Foundation Committee will award such fellowships and funds for research work, with the advice and cooperation of a Committee of three, one to be appointed by each of the following:

National Academy of Sciences
American Institute of Electrical Engineers
Society for the Promotion of Engineering Education.

This Committee is to be known as the "Charles A. Coffin Fellowship and Research Fund Committee" and the fellowships are to be known as the "Charles A. Coffin Fellowships." The expenses of the Committee are to be paid out of the income of the foundation.

Fifth. In each annual report of the General Electric Company a statement will be made of the awards under the "Charles A. Coffin Foundation," and other publicity will be given to such awards.

The Board of Directors of the General Electric Company has appointed as the "Charles A. Coffin Foundation Committee" the following officers of the Company:

Mr. A. W. Burchard
Mr. J. R. Lovejoy
Mr. E. W. Rice, Jr.
Mr. Gerard Swope
Mr. O. D. Young.

The Advisory Committee of the General Electric Company will administer the fund within the organization of the General Electric Company.

The following Committees to administer the fund and to act with organizations outside the Company have been appointed:

Committee to cooperate with the National Electric Light Association:

Mr. A. H. Jackson, Vice President
Mr. J. R. Lovejoy, Vice President.

Committee to cooperate with the American Electric Railway Association:

Mr. J. G. Barry, Vice President
Mr. A. H. Jackson, Vice President.

Committee to cooperate with the National Academy of Sciences, American Institute of Electrical Engineers and the Society for the Promotion of Engineering Education:

Mr. E. W. Rice, Jr., Honorary Chairman
Mr. A. H. Jackson, Vice-President
Mr. W. R. Whitney, Director of Research Laboratory.

Some Developments in the Electrical Industry During 1922

By John Liston

Publication Bureau, General Electric Company

It is our usual practice in the first issue of a new year to review the developments of the previous twelve months. Any one who has followed these articles can not fail to be impressed with the constant and persistent progress made in the electrical industry. Our present contribution shows that our curve of progress is still traveling on the up grade at a most satisfactory rate.—Editor.

The general industrial revival which characterized the year 1922 resulted in greatly increased activity in the production of all classes of electrical apparatus while the improvement in financial conditions rendered possible a much needed expansion in central station equipment and a resumption of development in numerous hydro-electric projects.

While progress in the electrical industry was mainly along established lines, there was a well defined tendency in practically every phase of electrical apparatus construction to concentrate the generation, transformation and distribution of electrical energy in units of greater capacities and with higher guaranteed efficiencies than in previous years.

The maximum rating for steam turbine generator sets was advanced to 62,500 kv-a. and for waterwheel generators to 65,000 kv-a. with corresponding increment in the capacities of the transformers and switching and auxiliary apparatus required.

The adoption of electric propulsion for ferryboats, Fig. 1, and the positive economies secured in their operation by this method opens up an interesting field of considerable importance in view of the great number of craft of this type which serve our inland and coastal waterways.

Automatic station practice made further technical and commercial gains with a steady increase in the unit capacities of the equipments and improvements in the design of the small sized but very important devices which make automatic operation not only feasible but fully as reliable as hand operation. While railway service continued to be the most active field for this class of apparatus, its use was further extended in central station systems and applied to numerous other industries.

Among other items of interest in widely varying fields were a new type of induction furnace for melting non-ferrous metals, the production of a highly efficient steam generator for use where surplus electrical energy is available, the "Pallophotophone" for recording and reproducing sound, the thirty-kilowatt incandescent lamp, radio and power tubes of unprecedented capacity, and further

Fig. 1. The First Electrically Propelled Ferryboat, the *Golden Gate*, placed in service in July, 1922

development of the million-volt testing set with its great possibilities for commercial and research work.

As in previous articles on this subject, the electrical apparatus, turbines, etc., referred to, are all products of the General Electric Company, but references to their development will serve as an indication of the tendencies in design and construction as well as the general trend of progress in the electrical manufacturing industry as a whole.

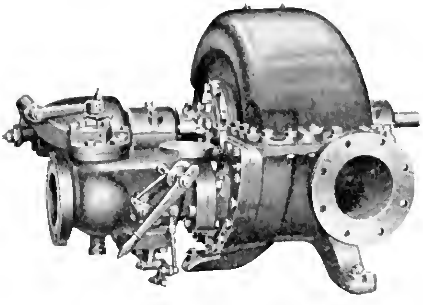

Fig. 2. Two-stage Mechanical-drive Curtis Steam Turbine

TURBINES

The improvements made in Curtis turbines of 7500-kw. capacity and larger during the year may be summarized as follows: Diaphragms except in the low pressure stages were so constructed that the nozzles can be easily removed and replaced. Nozzle partitions of superior mechanical design were produced for diaphragms in the low pressure stages. Both types of nozzles give a very high efficiency.

A steam sealed labyrinth type of packing with non-corrodible teeth was adopted and it is now standard practice to use cast steel for valve casings, turbine heads and other parts which may be subjected to temperatures above 450 deg. F. or more than 75 deg. F. superheat.

The vertical joint in the high pressure portion of the turbine casing was eliminated.

The standard emergency governor was redesigned so that it can be reset at 101 per cent of normal speed and the entire governor mechanism can be tested out without disconnecting the generator from the line.

There were under construction for the American Gas & Electric Company four 35,000-kw. base load turbines designed for the following steam conditions: Pressure, 500 lb. gauge, temperature, 725 deg. F. at the throttle, vacuum, 1 in. absolute. Special features are incorporated in the design which should produce a plant economy greater than any heretofore realized.

Among the large units under construction was a single casing turbine direct connected to a single generator which has a capacity of 50,000 kw. at 80 per cent p-f. or 62,500 kv-a. It will operate at 1200 r.p.m.

A new type of small steam turbine, Fig. 2, for driving centrifugal pumps and similar apparatus was placed on the market. It is made with a horizontally split wheel casing and is arranged with one, two or three stages to meet varying conditions of operation.

A complete line of small speed reduction gears, Fig. 3, was developed and they are already being extensively used for driving relatively low speed apparatus by means of turbines which normally run at higher speeds. These gears give speed ratios of from 2 to 1 up to 10 to 1 in various capacities up to 800 horse power.

ELECTRIC PROPULSION

At the close of the year, there were completed or under construction electric propelling equipments for seven double ended ferryboats, the first of which was completely equipped and placed in service in July.

This is an entirely new field for electric propulsion and, while less spectacular than the operation of battleships or seagoing merchant craft, is of considerable economic importance due to the efficiency with which the electrical equipment meets the peculiar power requirements inherent in double ended ferryboat operation.

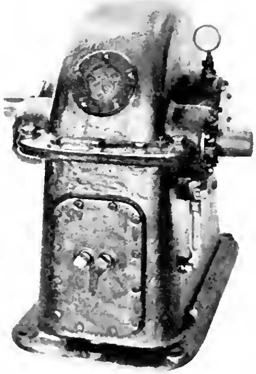

Fig 3. Single-reduction Gear for Steam Turbine Mechanical Drive

Three distinct types of electrical equipment are represented in these boats. Two of them are equipped for Diesel engine electric direct-current service, two for turbine electric direct-current service and three for turbine electric alternating-current service.

Two important factors determine the adoption of electric propulsion for these boats. First, they require propellers fore and aft; and second, the most efficient method of propulsion is by means of the stern propeller. Prior to the adoption of electric propulsion, numerous tests of existing ferryboats showed a high percentage of loss due to the bow propeller and this meant that, in order to get the required speed, excess power in the equipment had to be provided to take care of the bow propeller losses. With the adoption of electric drive, however, each propeller was provided with an individual motor and the desired speed of rotation of either the bow or stern propeller could be obtained for each, independently of the other.

The first electrically propelled ferryboat to go into service was the *Golden Gate*, Fig. 1, plying between San Francisco and Sausalito. Her propulsion equipment consists of two 500-h.p. Diesel engines, each direct connected to a 360-kw., 250-volt d-c. generator, Fig. 4, and two 750-h.p., 500-volt motors, Fig. 5, one on each propeller shaft. The control of the electrical equipment can be effected from either of the two pilot houses or the engine room as desired

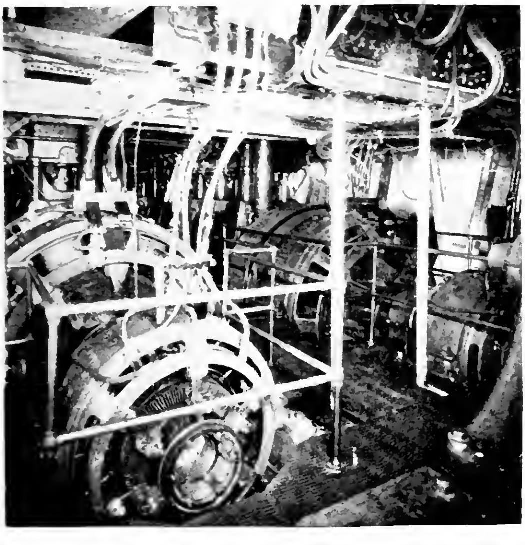

Fig. 4. 360-kw. Diesel-engine-driven Generators on Ferryboat *Golden Gate*

In operation, the stern propeller revolve at full speed, while the bow propeller is operated at a reduced speed. The power saved in driving the bow propeller in this way is of considerable economic importance.

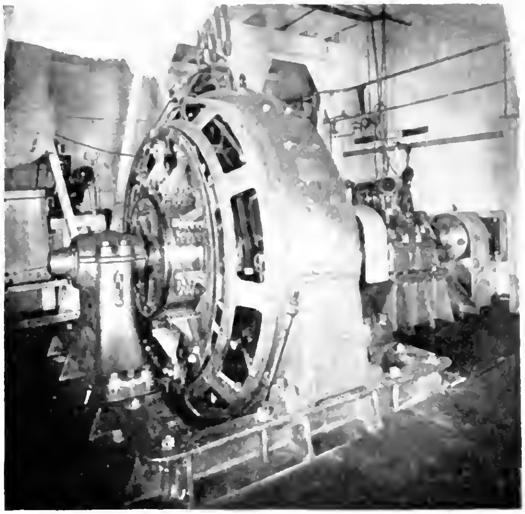

Fig. 5. One of the Two 750-h.p. Propelling Motors on Ferryboat *Golden Gate*

The different speeds of the motors are obtained by varying the voltage of the generators. After the proper speed for the bow propeller has once been determined, it can be automatically controlled. On the boats using alternating current, this feature is secured by providing the propeller motors with two sets of poles, with suitable provision for shifting from one to the other, through the control panel.

The equipment for each of the two San Francisco-Oakland boats consists of a geared turbine operating at 3600 r.p.m. driving a 1000-kw., 500-volt generator at 900 r.p.m., and two double-armature direct-current motors for the propellers, each rated at 1200 h.p., 500 volts at 125 r.p.m.

In addition to the above, there were under construction equipments for three ferryboats for operation between New York and Staten Island. The propelling equipment of each consists of one 2200-h.p., 3240-r.p.m., 2300-volt, 3-phase turbine generator set which will supply power to two 2100 100-h.p., 176 122-r.p.m., 36 52-pole, 2300-volt, 3-phase induction motors, these double-rated motors being designed to permit the operation of the bow propeller at the most efficient idling speed. These boats will be of exceptional size, having an over-all length of 216 ft. with 64-ft. overguard beam and a depth of hull amidships of 18.5 ft.

The state owned lines of Italy are being electrified as rapidly as possible, employing the 3-phase system, which has been in successful operation for a number of years. In the south of Italy, however, it is understood that extensive trials of 3000-volt direct current are being made, pending the electrification of the southern lines.

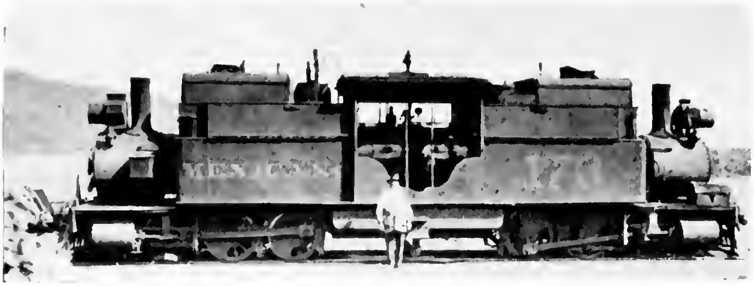
Fig. 6. Electric Locomotives will Replace this Double-ended Type of Steam Locomotive on the Mexican Railway between Mexico City and Vera Cruz

ELECTRIC RAILWAYS

Steam Road Electrification

There was evidenced a renewed interest in steam road electrification throughout the world but actual electrification work was more marked in foreign countries than in the United States. This was due to a certain extent to the much higher price of coal and other fuel, in these countries, than in the United States.

On the European Continent, decided progress was made by France, Switzerland and Italy. The French Government, following its decision to standardize on 1500-volt direct current, initiated a program of electrification on the main lines of the Paris-Orleans, the Midi, and the Paris-Lyons-Mediterranean systems, aggregating 5200 miles of track to be completed within 20 years. Contracts were placed, with affiliated companies representing the International General Electric Company, for more than $15,000,000. Included in this order is a large amount of substation and high tension line equipment to be supplied directly from the United States and a complete gearless electric passenger locomotive, as a sample equipment. A large quantity of other material built in accordance with G-E designs will be manufactured in France.

Included in the initial program is a changeover of the present electrified lines of the Paris-Orleans Railway at Paris (600 volts d-c.) and of the Midi lines in the south of France (single-phase) to 1500 volts direct current.

In other parts of the world high voltage direct current has been selected as the most economical method of handling heavy freight and passenger trains electrically. It is of interest to note that altogether there are now nine railroad electrifications at 2400

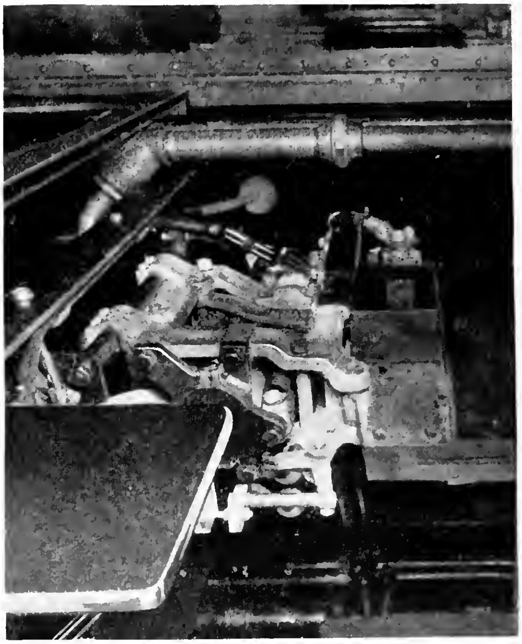
Fig. 7. Interior of New Locomotive for Imperial Government Railways of Japan showing High-speed Circuit Breaker

and 3000 volts direct current. With one exception the General Electric Company has taken the principal part in designating equipment for these roads. The distribution of these lines is as follows:

United States	2
Canada	1
South America	3
Mexico	1
Spain	1
South Africa	1

The successful operation of the Bethlehem Chile Iron Mines Company railway equipment, installed several years ago, was doubtless a factor in the selection of similar equipment for the Paulista Railway in Brazil and the Chilean State Lines between Valparaiso and Santiago.

The experience of the Butte, Anaconda & Pacific and the Chicago, Milwaukee & St. Paul Railways convinced the officials of the Mexican Railway that this was the proper system for the electrification of their severe grade line between Mexico City and Vera Cruz. The entire order for this equipment placed with the International General Electric Company includes ten 150-ton 3000-volt direct-current locomotives and a complete overhead distribution system. Energy will be purchased from the local power company and the entire 30 miles will be supplied from one substation.

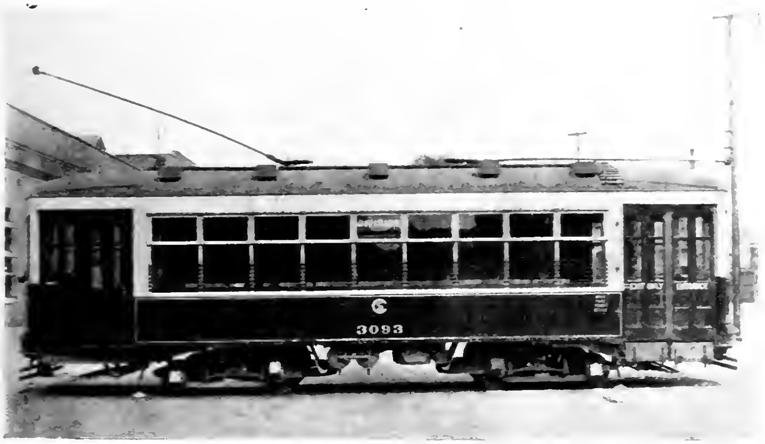

Fig. 9. Light-weight Chicago Surface Car

An interesting feature of this electrification will be the replacement of a novel type of steam locomotive, Fig 6, which was designed for operation in either direction and carries all weight on the driving axles The grades on the Mexican Railway include a maximum of $4\frac{1}{2}$ per cent and regenerative electric braking will be employed on the new locomotives.

Fig. 8. Light-weight Car, Detroit Railways

In the United States one of the most active prospective electrifications at present is that of the Illinois Central Railroad. An engineering commission was appointed some time ago and after giving the subject the most careful consideration over a period of many months decided to adopt the 1500-volt direct-current system with overhead trolley.

In order to take care of increased traffic, the Baltimore & Ohio Railroad recently ordered two 120-ton locomotives similar in most respects to those which they now have in operation.

The Imperial Government Railways of Japan laid out an extensive program of electrification and considerable equipment is already under construction. Two sample locomotives, Fig. 7, were shipped for trial on the 1200-volt lines between Tokio and Yokohama. All new electrifications will be at 1500 volts and all of the equipment will be capable of operating at this voltage.

The most extensive electrification initiated during the year was that of the South African Government Railways, totalling 174 miles of route. All of the high tension and substation equipment will be furnished jointly by the International General Electric Company and the British Thomson-Houston Company. An interesting feature of these substations is the use of automatic equipment in both single-unit and two-unit stations. All of the motor-generator sets will be of the three-unit type of 2000-kw. capacity each.

Fig. 10. Trackless Trolley Buses on Staten Island

Light Weight Double Truck Cars

In the city and interurban electric railway field the outstanding activity was the continued purchase of light weight safety cars and light weight double truck cars. The trend toward light weight has extended from the interurban lines to the city roads as is evidenced by the number of these cars completed or under construction at the close of the year for service in large cities:

Boston Elevated Railway	160
United Electric Railway, Providence	150
Detroit Street Railways (Fig. 8)	200
Chicago Surface Lines (Fig. 9)	45
City Railway Co. of Dayton	30

These cars are all equipped with light weight motors.

In addition to these, 21 other railway companies called for a total of 112 equipments for light weight double truck cars.

The demand for light weight safety cars continued and two-motor 25-h.p. equipments for 50 operating companies totaled 356, the larger items being as follows:

Illinois Traction System	95
Virginia Railway & Power	75
Louisville Railways	55
Stone & Webster Properties	106
Buffalo & Lake Erie Traction Co	25

The trackless trolley bus which has been operated with considerable success in New York City on Staten Island gave sufficiently good results to warrant the opening during the month of November of 10 miles of additional line with a new fleet of trackless trolley buses. All of these buses, Fig. 10,

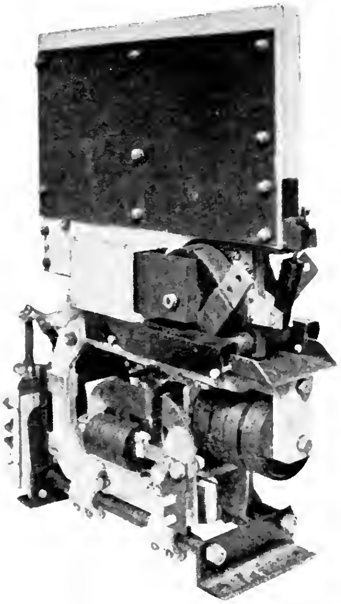

Fig. 11. New High-speed Circuit Breaker

are equipped with G-E motors, control and collecting devices.

Three sample trolley buses are also in operation; at Minneapolis, Minn.; Los Angeles, Calif.; and Petersburg, Va

High Speed Circuit Breakers

The high speed circuit breaker which was originally developed for the Chicago, Milwaukee & St. Paul Railway gave such creditable operating results that new designs,

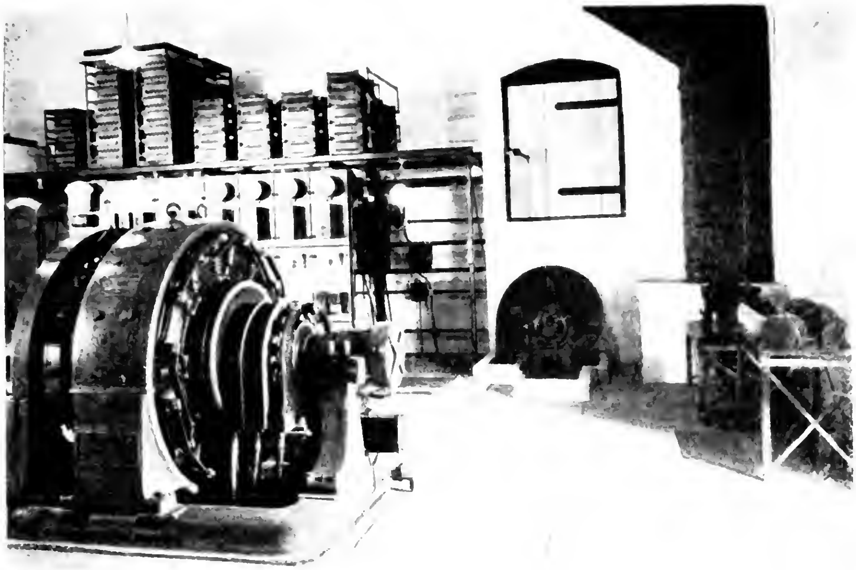

Fig. 12. Automatic Substation, Los Angeles Railway

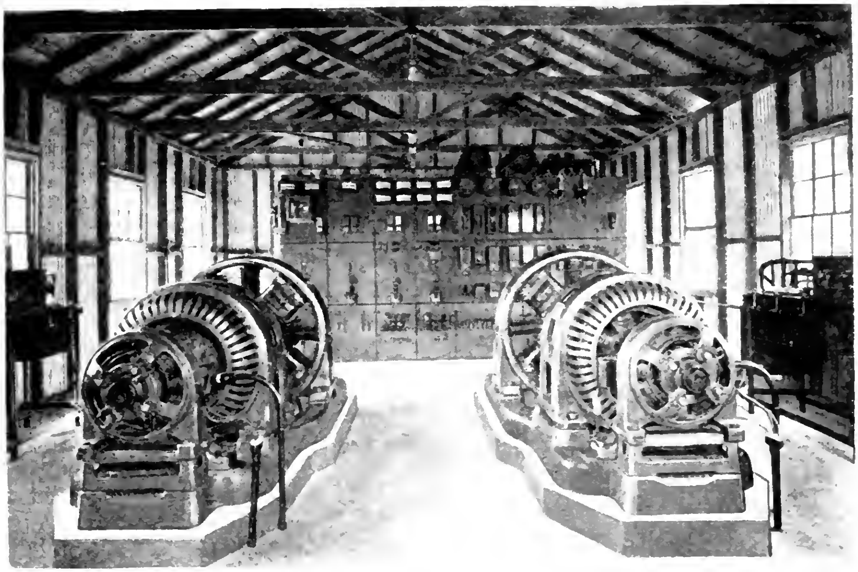

Fig. 13. Control Equipment for Two Synchronous Motor-generators. Star Coal & Coke Company, Red Star, W. Va.

Fig. 11, were perfected for other than 3000 volts and a large number of installations were made on 600-volt railways. These circuit breakers are being used not only for the protection of stations and individual machines, but also for feeder protection. The high speed of rupture insures 100 per cent protection wherever this device is in use and short circuits are interrupted without affecting the operation of the machines.

An accessory device which was placed in production is the electrically locked and unlocked turnstile and farebox which is being installed in the stations of the New York subways.

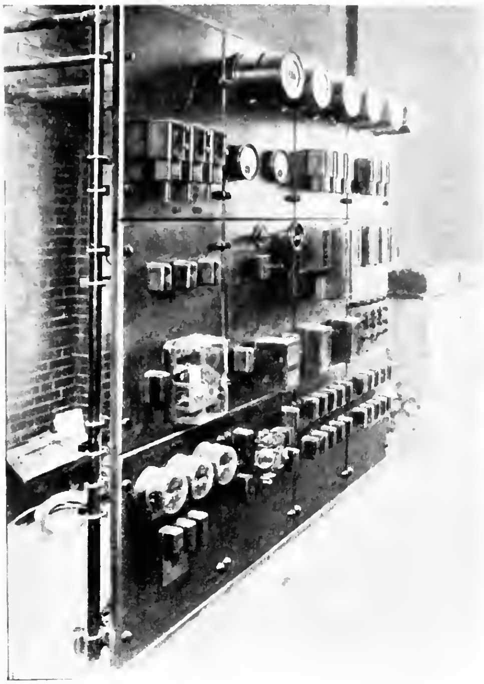

Fig. 14. Main Relay Panels and Master Switches, Station R, Kansas City Power & Light Company

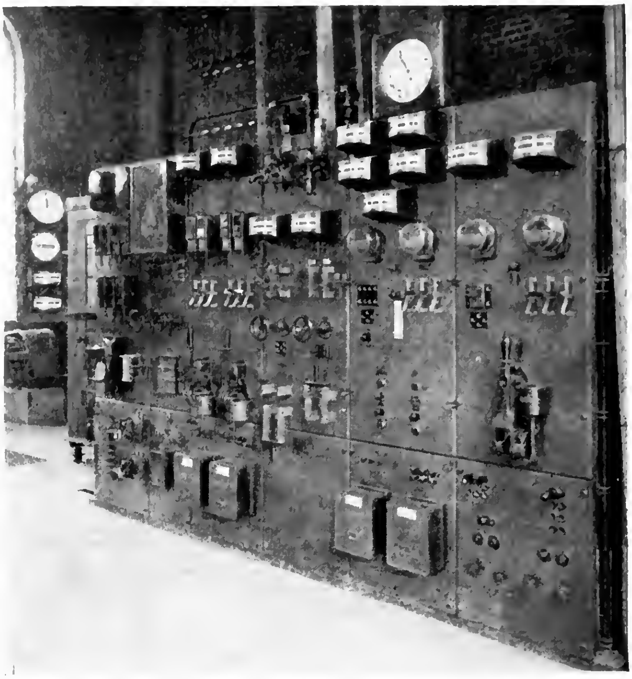

Fig 15. 5000-kw. Waterwheel Generator Automatic Control Equipment

Automatic Railway Substations

The electric railways continued to be the principal users of the automatic substation. The intermittent and widely varying load to which railway substations, Fig. 12, are subjected makes the automatic control with the load adjusting equipment particularly suitable for this service.

During the year work on some exceptionally large installations was begun not only in the United States but in foreign countries, the most notable foreign example being that of the South African Railways. In this country the Oregon Electric Railway will shortly place in service two stations of 1000 kw. and five of 500 kw. each on the 1200-volt lines operating out of Portland, Ore. When this equipment is installed all of the substations on this system will be automatic, with the exception of one in Portland. Another important group comprises five 750-kw. automatic control equipments for the substations of the Wilkes Barre & Hazelton Railway; and what is probably the largest order, in terms of total capacity, was placed by the United Railways of St. Louis for four 1000-kw. and two 2000-kw. control units. The Chicago, Aurora & Elgin Railroad will install two 1000-kw. units as the result of a number of years trial service of a 500-kw. station at Warrenville. These stations will also use the new supervisory control.

In order to supplement substation capacity on the New York Central Terminal electrification, an automatic substation will be installed at 110th St. midway between the present station at 50th St. and Station No. 2 at Mott Haven. This apparatus includes a

2000-kw. motor-generator set which will be remote controlled from one of the adjacent stations. Another 2000-kw. station is being installed by the Northwestern Elevated Railroad in Chicago. This is the first application of the automatic substation to metropolitan elevated service. Other interesting construction for automatic railway substations included the following:

		Kw.
Toronto Hydroelectric Commission....	Three	1000
Pacific Electric Railway..............	One	1500
Public Service Co. of New Jersey...	One	500
	One	1500
Cincinnati, Georgetown & Portsmouth St. Railway......................	Four	300

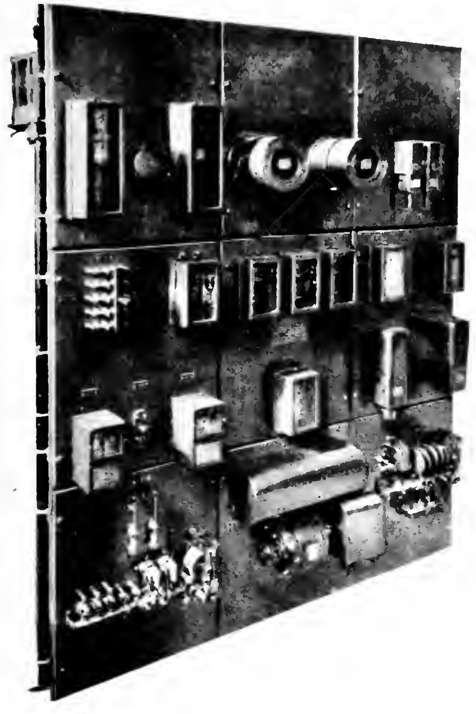

Fig. 16. Control of Motor-generators for Three-wire System, with drum controller mounted on center panel

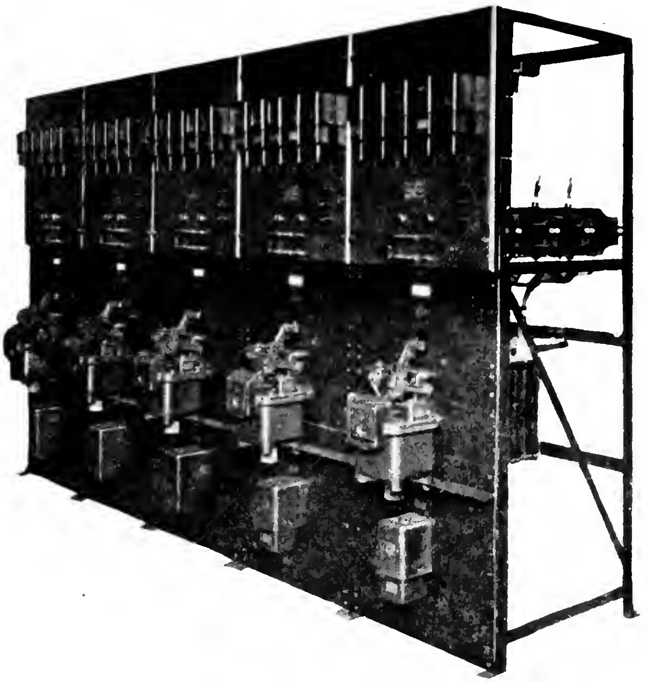

Fig. 17. Reclosing Alternating-current Equipment Utilizing Direct-current Solenoids

AUTOMATIC STATIONS

Important advances were made in automatic station control equipments, both in the number and capacity of installations and in the development of individual devices.

Operating engineers are aware of the successful and economic operation of those equipments which have been installed during the past few years and today no investigation of proposed installations or revision of existing ones is complete without a full consideration of the application of automatic control equipment.

While the railways were the first to recognize the advantages gained under automatic operation, other industries have rapidly followed their example with the result that this method has since been applied to practically all phases of power generation and distribution, except steam-driven units. Records to date show that there are more than 300 G-E automatic units installed, controlling about 200,000 kw. of rotating electrical machinery.

The largest, fully automatic, single-unit, hydro-electric station in the world, Fig. 15, has equipment which controls a 2300-volt, 5000-kw., 60-cycle waterwheel-driven generator.

An interesting application of the automatic principle was made, Fig. 14, to the existing a-c. distribution system of the Kansas City Power & Light Company. Because of the shifting of the load centers and the increase in load demand, extensions of the system became necessary. Automatic control equipment successfully and economically solved the problem of operating substations having two or more incoming lines with two or more transformer banks, and the usual number of outgoing feeders.

In the control of motor-generators for 125 250-volt 3-wire systems, Fig. 16, protection is obtained during overload periods by cutting in the differential field. The motor-driven drum controller, which fixes positively the sequence of operation of the equipment, was designed for panel mounting.

An outstanding development in mining service was the adoption by the Star Coal & Coke Company, Red Star, W. Va., of control equipment, Fig. 13, for a two-unit motor-generator station, which has relay control throughout and uses the automatic reclosing feeder feature as part of the regular equipment.

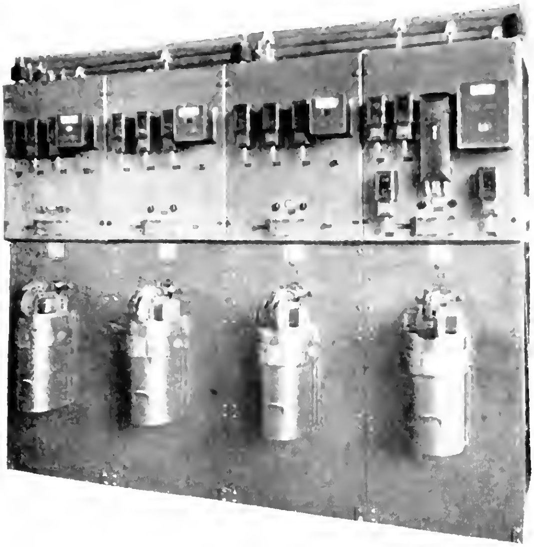

Fig. 18. Reclosing Alternating-current Equipment Utilizing Alternating-current Motor Mechanism

Alternating-current Reclosing Equipments

Among the new a-c. reclosing equipments produced, one utilizes a d-c. solenoid, Fig. 17, for reclosing, while in another an a-c. motor mechanism, Fig. 18, is used. These equipments will reconnect the load to the source at the end of a definite time interval after it has opened on overload or short circuit. If the overload remains and the breaker opens three successive times within a definite time interval, it is locked out and must be reset by hand before automatic operation can be resumed.

A new type of device, Fig. 19, was developed for this service, whereby one, two or three breakers may be reclosed three times in sequence. The device is motor operated and has three different time intervals between reclosures, with a maximum of approximately 2½ minutes for the total timing. If one or two breakers are locked out after three successive openings, the device will operate the remaining breakers. A slight positive time delay is provided between the reclosing of the breakers.

Direct-current Reclosing Equipments

Direct-current reclosing equipments were prepared for service in both 275-volt mining, and 600-volt railway service and have been standardized for use on stub end feed or combined stub end and multiple feed conditions.

The 275-volt equipment, Fig. 20, will automatically fulfill the following functions:

1. Disconnect the load from the source of power in case the voltage fails or the load exceeds a predetermined value.
2. The load will remain disconnected a definite minimum time interval regardless of the cause of the opening.
3. At the expiration of this time interval, it will immediately reconnect the load to the source of power, provided the voltage is restored, or the overload is reduced to a predetermined value. There will be no attempt to reclose as long as a short circuit or heavy overload exists.

For 600-volt railway service there was produced a reclosing equipment, Fig. 21, which makes use of the characteristics and advantages of the high speed circuit breaker. This equipment will:

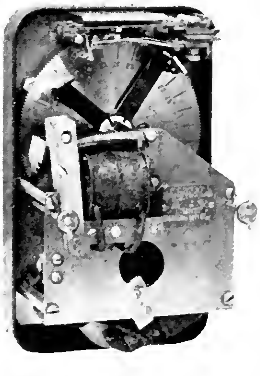

Fig. 19. Motor-operated Timer

1. Discriminate between short circuit and useful load such as is obtained on a typical railway feeder, and will allow current to be supplied for a maximum

time to all useful loads, but will instantly disconnect the equipment from loads that indicate that power is being dissipated in short circuits.

2. Disconnect the equipment if current is beyond a maximum value, by means of "steady" overload setting of the high speed breaker.
3. Allow the breaker to remain closed during peak currents (below value stated in No. 2), which are caused by useful loads; but if the rate of rise of current is such as to indicate a short circuit, the breaker will:
4. Trip out with high speed.
5. Operate on either stub end or multiple feed in either direction.
6. "Trip free" from resetting mechanism if closed on overload, as in the case of manual operation (which is provided for this equipment), with the above mentioned high speed characteristics.
7. Open due to voltage failure.

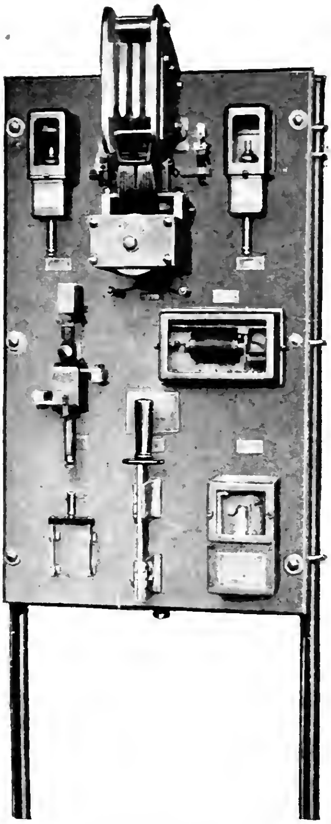

Fig. 20. 275-volt Direct-current Feeder Reclosing Equipment

The application of control equipment to a single unit synchronous motor-generator set for 600-volt railway service utilized a panel-mounted drum controller and a new type of field and synchronous speed relay, the resistor type of load limiting equipment being used.

Fig. 21. 600-volt Railway Service Reclosing Equipment

For a single-unit synchronous motor-generator 3-wire system, all devices, relays and auxiliary switches were mounted on the front of the panel. The equipment comprises relays for load control and the differential field type of load limiting equipment and a panel-mounted controller.

Supervisory Systems

Due to the rapid increase in the number of automatic stations, there was a demand for some means of centralized supervision over these units in a large power system. This demand was met successfully by two different methods of control and indication.

The first system known as the Selector Type is for use where but few operations are desired per station and where the stations cover a wide area. A typical example of this is in interurban railway service. The control wires in this case are of the ordinary telephone size, three in number, and run continuously from station to station. Impulses of alternate unidirectional current are sent by code keys in the dispatcher's office to operate a particular selector in the outlying station which in turn closes a local circuit and performs a specific operation. Auxiliary switches are mechanically closed when the operation is completed and this in turn causes the release of a particular code which on the local motor drives a sending key. This operates a selector in the dispatcher's office which in turn lights a red or green lamp, indicating at all times the electrical position of the apparatus in the outlying station.

Fig. 22. Rotor Spider of 40,000-kv-a Generator for Shawinigan Engineering Company, Ltd., Canada

The second system is of the distributor type which finds use in power systems within a radius of 20 miles and where a large number of operations per station are required. Two cabinets, one in the dispatcher's office and one in the outlying station, have apparatus to control and indicate 50 circuit breakers.

The distributors operate in synchronism and distribute either a positive or negative impulse, originating at a particular dispatcher's key to a certain two-position relay at the outlying station. This relay closes one of two local circuits depending on whether it receives a positive or negative impulse, and this action performs the desired operation. Originating from an auxiliary switch on the controlled apparatus, an impulse is similarly sent back over a separate wire to operate a relay in the dispatcher's office and indicate the electrical position of the controlled apparatus. Four wires are required between each pair of distributors.

New Devices

(*a*) A busbar thermal relay which provides a reliable means of insuring protection to feeders from overheating. It disconnects the feeder in case of overheating and reconnects it when it has cooled to a safe operating temperature.

(*b*) A slip relay to perform the necessary switching operations when a synchronous motor is pulled out of step by a heavy overload. This is a balanced relay which operates on line and exciter frequency.

(*c*) A new field relay constructed with a heavy copper dampening sleeve which prevents it from dropping out on a momentary dip in the field current. Because of its construction it will not pick up on a-c. but does on d-c. and this characteristic makes it suitable for a synchronous speed indicating device when connected across a synchronous converter armature. Also a similar type except that the dropout is instantaneous, and because of its low pickup and dropout values it is used as an exciter or generator relay.

(*d*) Another relay of similar construction is used as a field building relay, which permits the rapid building up of a generator field by short circuiting a portion of the field resistance and then opening its contacts at a predetermined value of voltage.

(*e*) A new type of notching relay which is adjustable and functions after two, three or four operations, depending on the setting.

(*f*) A high speed circuit breaker with added trip free and discriminating features. The trip free feature permits the automatic tripping of the breaker if overload exists when it is reset. The discriminating feature is obtained by the use of an inductive shunt, which sends the current through the "bucking bar" when the rate of rise of current is rapid as in the case of a short circuit, and this opens the breaker. On a normal rise in current as in the case of a useful load, the inductive shunt takes its share of the current and the breaker does not open unless the maximum setting is reached.

(g) An a-c. motor mechanism for operating oil circuit breakers with the least amount of energy demand, which makes use of the energy stored in a rotating mass to operate the breaker. It has found particular application in a-c. automatic reclosing equipments.

WATERWHEEL GENERATORS

There were several notable hydro-electric developments undertaken during the year as well as a considerable expansion of existing plants and, as a result, a large number of machines of exceptional size were produced. At the close of the year, there were under construction waterwheel generators aggregating about 600,000 kv-a. in capacity.

The shipments during the year included a vertical shaft unit for Shawinigan Engineering Company, Fig. 22, rated at 40,000 kv-a., 11,000 volts, 3 phase, 60 cycles, for operation at 138⅓ r.p.m. At the time of its completion, this was the largest G-E waterwheel generator constructed.

There were also completed three 20,000-kv-a., 6600-volt, 100-r p.m. generators for the Alabama Power Company, and one 11,750-kv-a., 4200-volt, 106-r.p.m. unit for the Washington Water Power Company.

Among the foreign shipments were included four 13,750-kv-a., 6600-volt, 180-r.p.m. and two 13,000-kv-a., 6600-volt, 375-r.p.m. units for Japan. These were all vertical shaft machines. There were also two horizontal shaft machines each rated at 14,444 kv-a., 6600 volts, 600 r.p.m. for the Mexican Light and Power Company.

Among the units under construction were two of the largest vertical shaft waterwheel-driven generators in the world. They are rated at 65,000 kv-a., 12,000 volts, 25 cycles, 107 r.p.m. and are being built for the Niagara Falls Power Company.

The last three years have seen notable advances in the unit capacity of this type of G-E machine, the maximum for the three years being 1920, 32,500 kv-a.; 1921, 40,000 kv-a.; 1922, 65,000 kv-a.

Each of the 65,000-kv-a. units has a 650-kv-a., 2200-volt exciter mounted between the rotor spider and the upper bearing bracket. The stators of these machines each weigh 443,000 lb., rotor and shaft 767,000 lb. and miscellaneous parts 168,000 lb., the suspension thrust bearing having imposed on it a live load of 1,250,000 lb. The thrust bearing housing is provided with water coils for cooling the lubricating oil, and in addition, a small oil circulating system for the bearing, equipped with a filter, is provided.

These large machines have the highest guaranteed efficiencies ever given by waterwheel generators. At 65,000-kw unity power-factor, the efficiency is 98.1 per cent and at 0.9 power-factor, it is 97.8 per cent.

An unusual extension to an existing hydro-electric development was provided for by the construction of a 31,250-kv-a., 13,200-volt, 60-cycle, 156½-r.p.m. vertical generator, Fig. 23, for the Tallassee Power Company. This unit is designed for mounting on top of an existing 18,000-kv-a., 36-cycle generator which is provided with a waterwheel of sufficient power to operate the larger machine.

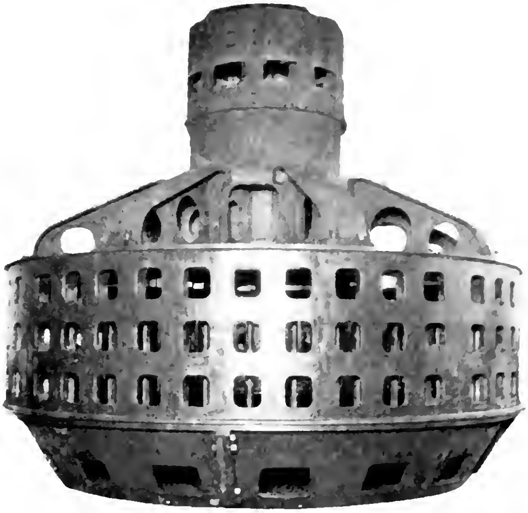

Fig. 23. 31,250-kv-a. Generator to be mounted on top of an existing 18,000-kv-a. vertical-shaft waterwheel generator

This special arrangement is due to commercial conditions and will permit the generation and sale of 60-cycle energy during periods when the 36-cycle service is not required. It also renders it possible to utilize the combined unit as a frequency changer if required.

Among the large generators under construction for foreign shipment there are two vertical shaft 25,000-kv-a., 6600-volt, 50-cycle, 125-r.p.m. units for the Brazilian Hydro-electric Company and five horizontal shaft 22,222-kv-a., 11,000-volt, 60-cycle, 300-r.p.m. units for Japan. These latter machines are intended for a hydro-electric development in Formosa and are the largest machines of their type produced for foreign shipment. Their installation will complete the largest capacity hydro-electric station outside of the United States. Other construction for Japan includes three 14,444-kv-a., 11,000-volt, 50-cycle generators.

As the result of assistance given to a hydroelectric plant in India in rebuilding four 10,000-kv-a. generators originally supplied by a European manufacturer, an additional generator rated at 10,000 kv-a., 5000 volts, 50 cycles, 300 r.p.m. is being constructed.

Construction for domestic installation includes four 20,000-kv-a., 11,000-volt, 250-r.p.m. units for the Hetch Hetchy project, one 17,500-kv-a., 6600-volt., 375-r.p.m. unit for the Southern California Edison Company and two 12,500-kv-a., 6600-volt, 300-r.p.m. units for the Western States Gas and Electric Company.

SYNCHRONOUS CONDENSERS

While the maximum rating of previous years for these machines was not exceeded, there were under construction two units of record size.

One of these is for the Department of Public Service, Los Angeles, California. It is rated at 30,000 kv-a., 7920 volts, 60 cycles, 600 r.p.m. It can also be operated at 50 cycles, 500 r.p.m. and under these conditions it has a rating of 25,000 kv-a., 6600 volts.

The other unit is rated at 30,000 kv-a., 6600 volts, 50 cycles, 600 r.p.m., and is intended for the Southern California Edison Company. It is a duplicate of a machine already installed.

In addition to these, there were two synchronous condensers which exceeded in unit capacity any machines of this type previously constructed for foreign installation. They are rated at 25,000 kv-a., 11,000 volts, 60 cycles, 600 r.p.m. and are for the Nippon Electric Company of Japan.

SYNCHRONOUS MOTORS

A new form of synchronous motor, Fig. 24, for high starting duty was developed, which obviates by its method of operation the disadvantages heretofore considered inherent in synchronous motor drive where overload starting conditions are involved.

The motor is so constructed that it is possible when starting to bring the armature, which is normally the stator, up to synchronous speed without any reference to the load. When the armature is at synchronous speed, the field is applied in the ordinary way and the rotor gradually brought up to speed. The speed of the revolving stator is meanwhile brought down to zero by means of a powerful band brake which is locked in position when synchronous speed of the load has been attained.

By this method, the torque is applied gradually and the driven machine is brought up to speed without a shock: Thereafter the motor functions, with its stator held stationary by the band brake, as an ordinary synchronous motor.

By means of this method of rotating the stator, this type of motor can develop a starting torque of from 150 per cent to 300 per cent of normal throughout the entire starting period, as the torque available at the shaft is equal to anything below the pullout torque of the motor and is proportional to the current.

The new design economizes space as compared with previous methods of synchronous motor drive in that it eliminates the necessity for clutches between the motor and the load and the floor space normally required for additional bearings.

This new type of motor will make it possible to secure full advantage of the high power-factor characteristics of the synchronous motor without the disadvantages of additional equipment which have heretofore been necessary when the synchronous motor was required to start under overload.

STEEL MILLS

During the year there was added 40,820 h.p. (normal continuous rating) to the existing capacity of main roll drives installed by the General Electric Company, bringing the total capacity to 572,800 h.p.

The fact that the substitution of electric main roll drives for existing steam driven units will show an excellent return on the investment is continually being demonstrated by additional installations. During the year, a number of steam engines were replaced by motor drive.

Probably foremost in importance is the equipment for the Youngstown Sheet and Tube Company for the electrical operation of a 30-in. reversing Universal skelp mill which will replace a twin simple reversing engine. The rolling mill motor is rated 4000 h.p. continuously at 80 r.p.m. and 11,500 h.p. maximum at 75 r.p.m. The maximum speed is 135 r.p.m. The flywheel set which furnishes power to the reversing motor consists of a 2500-h.p., 500-r.p.m., 6600-volt, 25-cycle induction motor, two 1800-kw., 650-volt direct-current generators and steel plate flywheel. This is the third engine-driven mill to be changed over to electric drive by the Youngstown Sheet and Tube Company, as early in 1922 their two sheet mill engines were replaced by two 2000-h.p., 250-r.p.m., 6600-volt, 25-cycle induction motors.

Another important installation which supersedes an engine drive is that of a motor rated 1850/1450/925 h.p., 120/94/60 r.p.m., 6600 volts, 25 cycles, which is direct connected to a 16-in. hand bar mill at the Lackawanna Plant of the Bethlehem Steel Company. This motor is provided with a double range Scherbius speed regulating set by means of which speed control is obtained from 60 up to 120 r.p.m.

At the Aliquippa Works of the Jones and Laughlin Steel Company a 5750-h.p., 94-r.p.m., 6600-volt, 25-cycle motor was installed to drive 21-in. and 18-in. billet mills, which were previously engine driven.

The engine which drove the 33-in. structural mill at the Homestead Works of the Carnegie Steel Company was replaced by a 4000-h.p., 83-r.p.m., 6600-volt, 25-cycle induction motor with flywheel which is a duplicate of that driving the Liberty 110-in. plate mill at the same plant.

Electric drives were under construction for a large number of new steel mill installations, among which are the following:

For driving a 40-in. reversing blooming mill at the Riverside Works of the Otis Steel Company, an electrical equipment duplicating that which drives the 40-in. mill at the Sparrows Point Plant of the Bethlehem Steel Company. This equipment consists of a reversing motor rated 6500 h.p. continuously at 50 r.p.m. and 17,000 h.p. maximum at 45 r.p.m. The maximum speed is 120 r.p.m. The flywheel set which furnishes power to this reversing motor consists of a 3750-h.p., 375-r.p.m., 6600-volt, 25-cycle induction motor, two 2700-kw., 600-volt direct-current generators and a 50-ton flywheel. Further installations at this same plant consist of electric drive for a 20-in. hot strip mill, which consists of one 1800-h.p., 500-r.p.m., 6600-volt, 25-cycle constant-speed induction motor which drives the roughing stands. The first three finishing stands are driven by three 1500-h.p., 280/420-r.p.m., 600-volt, shunt-wound, direct-current motors which are geared to the mills. The last three finishing stands are driven by direct-connected, 600-volt, shunt-wound, direct-current motors, one 1800 h.p., 115/173 r.p.m., one 1800 h.p., 134/201 r.p.m., one 1800 h.p. 153/230 r.p.m. Power for the 600-volt direct-current rolling mill motors is obtained from three 1500-kw. synchronous converters.

A high speed 10-in. rod mill is being installed at the Portsmouth Plant of the Whitaker-Glessner Company, which will be driven by one 2870/1435-h.p., 400/200-r.p.m., 600-volt, direct-current motor and three 800/363-h.p., 706/320-r.p.m., 600-volt, direct-current motors.

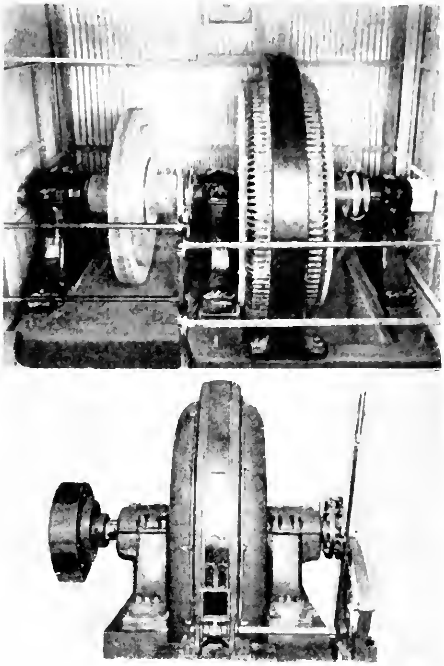

Fig. 24. Old form (above) new form (below) of Synchronous Motors of identical rating

For auxiliary drives it has been almost universal practice in the past to install totally enclosed mill-type, direct-current motors, Fig. 25, but the engineers of the Otis Steel Company have departed from this practice and will use a number of open type, direct-current mill motors, Fig. 26, whose performance under the usual steel mill conditions will be watched with interest.

In June the electrical equipment for driving the 14-in. hot-strip mill at the plant of the Trumbull Steel Company was put into successful operation. This installation, Fig. 27, consists of a 1250-h.p., 175/350-r.p.m. motor, geared to four 14-in. roughing stands, one 1250-h.p., 175/350-r.p.m. motor, geared to two 14-in. intermediate stands, one 800-h.p., 200/400-r.p.m. motor, one 800-h.p., 231/462-r.p.m. motor, one 800-h.p., 256/512-r.p.m. motor, and one 800-h.p., 275/550-r.p.m. motor direct connected to the last four 14-in. finishing stands. All motors are 600 volts direct current with speed control obtained by control of the motor field. Power is obtained from two 2300-kw. synchronous motor-generator sets.

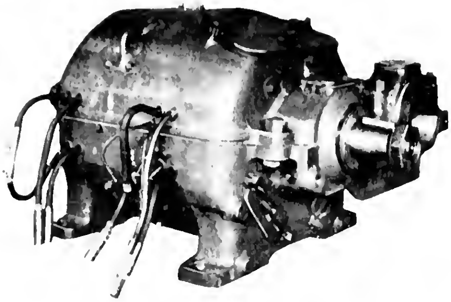
Fig. 25. A Typical Enclosed Mill-type Motor

It was necessary to depart from the usual practice of installing slip-ring type induction motors with speed regulating sets and to use direct-current motors on account of the special control required to maintain the exact speed relation between stands which is essential in a continuous mill of this type. So far as is known, this is the first installation of a high speed continuous mill with finishing stands driven by individual motors.

The generating equipment in steel mill power plants was increased during the year by twelve installations of Curtis steam turbine driven generators totaling 52,700 kw. In this list are included four 10,000-kw. machines, one for the Jones and Laughlin Steel Company, one for the Homestead Works of the Carnegie Steel Company, one for the Riverside Works of the Otis Steel Company and one for the Sparrows Point Plant of the Bethlehem Steel Company.

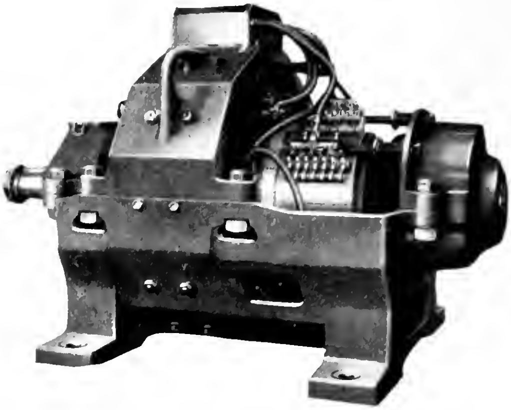
Fig. 26. A Typical Open Mill-type Motor

ELECTRIC WELDING

A new design 400-ampere constant-potential arc welding set, Fig. 28, was produced. It is furnished with three resistors, two of

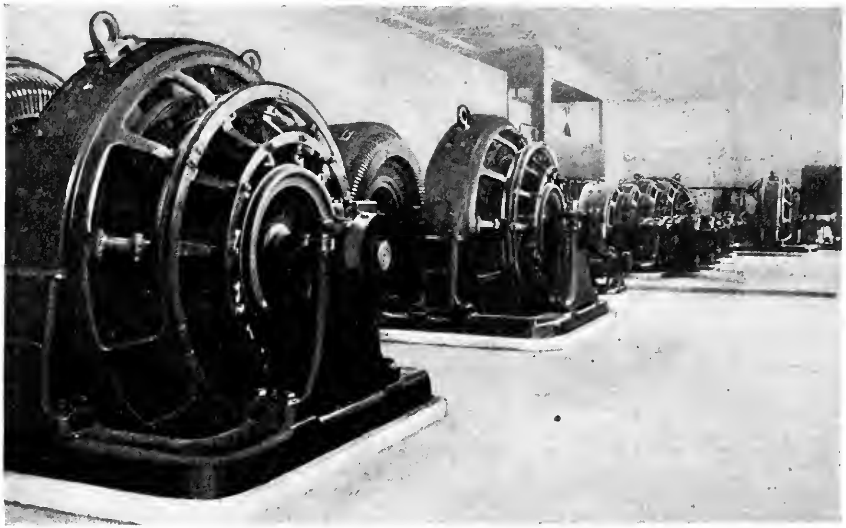
Fig. 27. Motor Room of 14-in. Hot-strip Mill of Trumbull Steel Co.

200 amperes for metallic arc welding and one of 300 amperes for carbon welding. The 200-ampere resistors for metallic welding have a current range from 40 to 200 amperes in 10-ampere steps. The 300-ampere resistor for carbon welding has a range from zero to 300 amperes in 30-ampere steps. The combination of a 200-ampere and a 300-ampere resistor for carbon welding has a current range from 20 to 100 amperes in 5-ampere steps, from 100 to 180 amperes in 10-ampere steps, from 180 to 300 amperes in 15-ampere steps and from 300 to 400 amperes in 20-ampere steps. It is possible to use the two 200-ampere and the one 300-ampere resistor each independently of the other, thus allowing two men to work at metallic arc welding and one man on light carbon work at the same time.

A new design of portable semi-automatic welding equipment, Fig. 29, allows the operator to direct the arc as required by the conditions of the work, yet retains the continuous feed features of the automatic equipment.

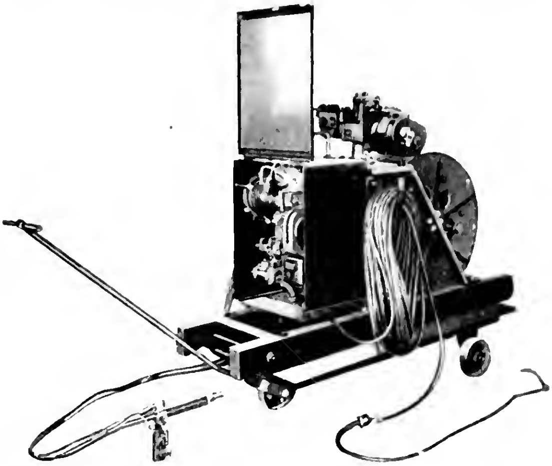

Fig. 29. Portable Semi-automatic Welding Equipment

A NEW INDUCTION FURNACE

In its earlier and simpler form, Fig. 30, the induction furnace consists of an annular channel shaped crucible in which the entire charge is contained, and a primary winding interlinking with a laminated iron core which is common to both. When an alternating voltage is impressed on the primary winding, heat is generated by a secondary current flowing around the circuit of molten metal within the crucible. The very low resistance of the secondary circuit, combined with the high leakage reactance, result in very low power-factor, and make it difficult to get large amounts of power into this furnace. These objectionable features are exaggerated with higher conductivity metals. It is, in fact, impossible to operate the furnace on such metals as brass and copper, since the magnetic field surrounding the secondary becomes so powerful as to cause magnetic choking. It severs the continuity of the molten metal in the channel, causing periodic interruptions of the current and a continuous agitation of the molten metal. All of these difficulties and disadvantages have been overcome in the new furnace.

In the general construction of the new furnace, Fig. 31, the melting pot and molten

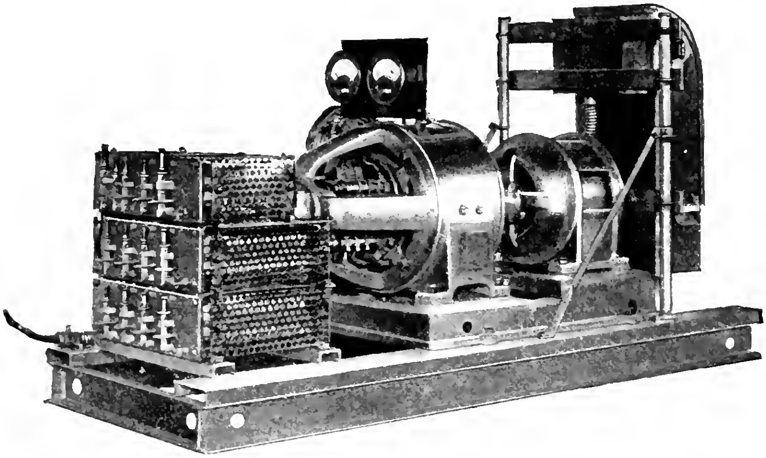

Fig. 28. 400-amp. Constant-potential Arc-welding Set

metal secondary or heating element have been segregated The latter is in the form of a hollow cylinder of considerable length, which surrounds the cylindrical primary winding and core. It is located beneath the melting pot and communicates with it through separate ports or ducts from both ends of the cylinder. The secondary circuit completes itself without passing through the melting pot.

The force of electro-magnetic repulsion, which exists between primary and secondary in all transformers, is utilized in this furnace to produce a brisk automatic circulation of the molten metal between the heating circuit and the melting pot. The axial displacement between the primary and the secondary cylinders results in a variation throughout the length of the secondary of the fluid pressure caused by this force, giving maximum pressure at one end of the cylinder and minimum pressure at the other. This results in a flow of the metal from one end of the heating cylinder to the melting pot through one of the ducts, and from the melting pot through the other duct to the other end of the cylinder. In the cylinder itself, the flow is in an axial direction, transverse to the direction of the secondary current, and the flange shaped enlargements at the ends of the cylinder assist in distributing the incoming stream around one end, and in collecting the outgoing stream at the other. A free, uni-directional circulation of the metal is thus obtained, in a stream of large cross section, the rate of which may be varied as desired by merely shifting the axial position of the primary winding.

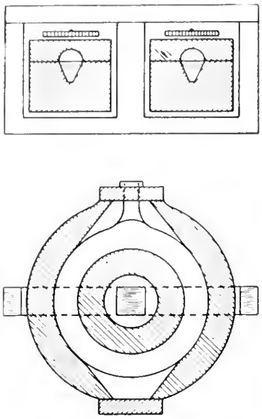

Fig. 30 Vertical and Horizontal Sections Illustrating the Simplest Form of Induction Furnace. The primary winding is shown in section over the horizontal ring crucible

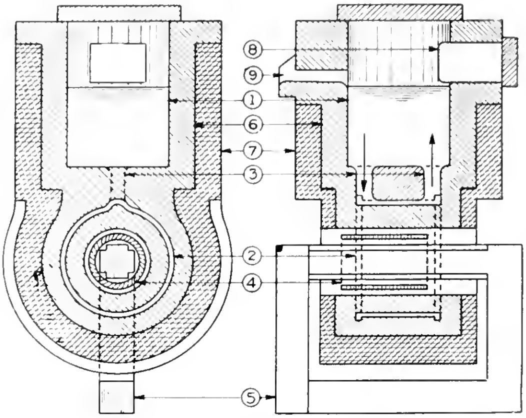

Fig. 31. Two Vertical Sections at Right Angles to Each Other Illustrating the General Form of the New Repulsion Induction Furnace

(1) Molten metal bath in the melting pot. (2) Molten metal secondary cylinder in which heat is generated by induced current. (3) Ducts for uni-directional circulation of the molten metal. (4) Primary winding. (5) Laminated iron core. (6) Refractory lining. (7) Thermal insulation. (8) Charging door. (9) Pouring spout.

Although the heat is generated and utilized in entirely different parts of the furnace, this free, automatic, uni-directional circulation results in a small variation in temperature throughout the bath. Another result secured with this circulation is the elimination of the possibility of magnetic choking. Under its own head, plus atmospheric pressure, metal would be supplied to the heating cylinder through the ample duct provided for this purpose much more rapidly than it could be forced out through the other duct, against this same head, by the magnetic leakage field which constitutes the medium of repulsion between primary and secondary. These results make it practicable to force this furnace to any extent which is feasible for the primary winding and core, and particularly adapts it for the melting of high conductivity metals, such as copper, as well as for metals of lower conductivity. The size and rating for furnaces of this type is limited, if at all, only by such considerations as mechanical strength and reliability of the refractory linings, which may appear in large sizes.

Although this furnace, Fig. 32, is new, it is already being used with pronounced success on brass, bronze, and copper, and its application will undoubtedly extend to other metals, both non-ferrous and ferrous. The power-factors obtained, even with the high conductivity metals, approximate those obtained with induction motors. Another important advantage which has been incorporated in the commercial development of this furnace consists in the preformed and prefired linings, which can be installed in a fraction of the time and at a fraction of the cost required for the ordinary rammed lining. All parts of these linings can be thoroughly inspected before installation, thus insuring a good lining.

INDUSTRIAL HEATING

There was a notable expansion in the use of industrial heating devices, ovens, furnaces, etc., employing metallic resistor heating units. As compared with 1921, the volume of applications of this nature for 1922 showed an increase of more than 50 per cent in kw. capacity. This particular method of applying electricity for industrial heating has now been on a commercial basis for about six years during which time the heating units installed have aggregated about 500,000 kw. in capacity.

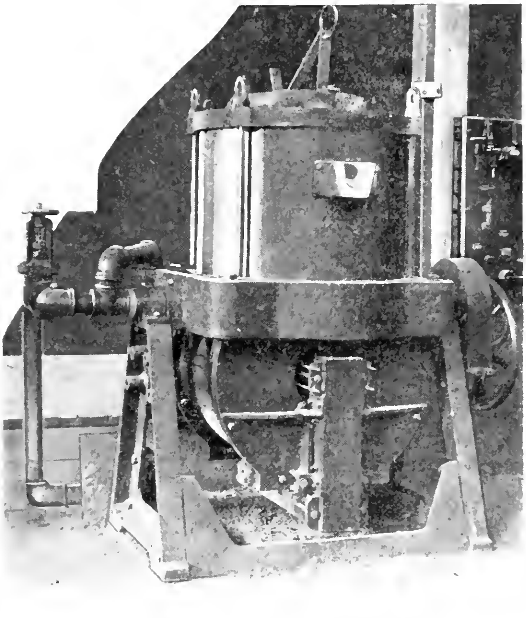
Fig. 32. 75-kw. Repulsion Induction Furnace

ELECTRIC STEAM GENERATOR

As the result of several years investigation and the production and test of various types of electrically heated boilers under industrial conditions, a new type of steam generator was produced, which gives high efficiency for the current consumed and insures the utmost simplicity and reliability in control and operation.

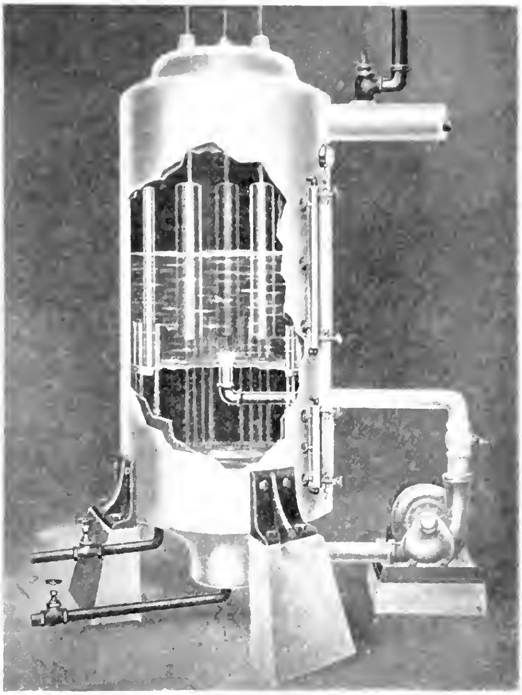
Fig. 33. Internal Arrangement of Electric Steam Cenerator

The new steam generator is a compact self-contained unit. In the shell there are two compartments, Fig. 33, the upper where the steam is generated by passing electric current from the electrodes through the water, and the lower, which serves as a hot well to which water is supplied by a feed water pump.

Water is continually circulated from the hot well to the electrode chamber by means of a centrifugal pump. More water is circulated than evaporated and perforations in the bottom of the upper compartment permit the excess water to drain back into the hot well. By throttling the discharge pipe of the circulating pump a definite water level can be maintained in the electrode chamber and thereby a constant energy input is secured which is in no way dependent upon the operation of the feed water pump. An automatic float type of feed water regulator maintains an adequate amount of water in the hot well.

The energy input into the generator can be either increased or decreased by simply adjusting the throttle valve in the circulating pump discharge line. When it is desired to reduce the power input into the generator it is unnecessary to remove any water from the shell.

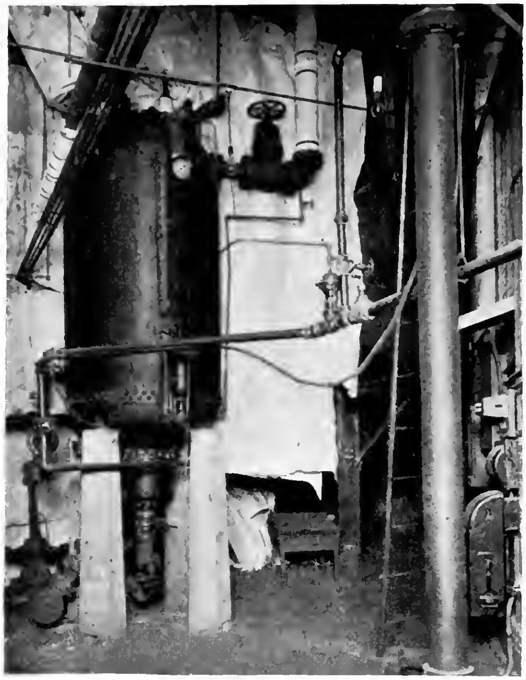

Fig. 34. Electric Steam Generator Installed in a Paper Mill

By this ingenious combination of the hot well, circulating pump, and steam generator, all the water in the system is at practically the same temperature so that if the steam pressure drops, due to an increased demand, more of it is immediately turned into steam than in the types of boilers where only the upper section of the water is in contact with the electrodes.

By the use of suitable auxiliary apparatus, it is possible to maintain either constant steam pressure, constant temperature, constant power input, or variable power input so that the generator will absorb all excess power above that required by the normal power demand.

There has already been established a wide field of application for the electric steam generator and a brief outline of some of the conditions under which its operation may be profitably undertaken may be of interest:

The utilization of surplus power when available in industrial plants, Fig. 34, having their own water power generating equipments. Many industries must maintain steam on Sundays and holidays during which the total steam load can economically be taken over by the electric steam generating equipment, banking the fires of the coal furnaces, or shutting down oil fired boilers.

When industrial concerns purchase power on a fixed annual charge up to a certain maximum capacity, it is practically impossible to maintain this maximum capacity throughout the year, many kilowatt-hours of energy are paid for and not used. Some power systems have an excess of water power during the off peak period of the day which, due to lack of storage capacity, would be wasted. They must also maintain their boilers under pressure to carry the peak loads. With these conditions and especially where oil is used as fuel it would pay to put out the oil fires and maintain the boilers under pressure from electric steam generators using the surplus power which would otherwise be going over the dam.

There are often instances in industrial plants where comparatively small amounts of process steam are necessary at a considerable distance from the boiler house. It will often be found more profitable to transmit power from the generating plant and install a steam generator at the point of utilization than to transmit the steam long distances.

Another application which is in use both in Canada and the United States is for central power stations, that have excess energy, to install and maintain electric boilers in industrial plants and sell the energy on the basis of metered steam.

ELECTRIC DYNAMOMETERS

The electric dynamometer was successfully introduced as a standard machine for the service station and garage, giving them facilities for testing out overhauled jobs and putting customers' cars in shape in the same way that new production in the automobile factories is tested out.

A special machine was developed for this purpose and a complete electrical-mechanical unit constructed for taking the power from the rear wheels of the car. The unit includes the drums upon which the rear wheels run, together with a shaft, bearings, frame dynamometer, transmission and control. The car may be loaded with the driver in the seat, Fig. 35, and the load and speed changed through a wide range by the handle of an enclosed safety-type controller within easy reach of the driver. This dynamometer forms a convenient, accurate means of testing the car under full load through a wide range of speeds right in the service shop; practically reproducing road conditions.

Fig. 35. Dynamometer Chassis Test System for Garage Service

SPRAGUE ELECTRIC HOISTS

A new hoist was brought out, having a capacity of ½ ton and 1 ton and designed for manufacture in large quantities as a general purpose portable unit. The lift is 25 feet and the speed 25 feet per minute. It is built upon the unit principle, and consists of six sub-assemblies which are carried through manufacture separately and can be stocked separately. These sub-assemblies are the motor, the controller, the limit switch, the transmission, the brake, and control.

There are fewer parts in this hoist, Fig. 36, than in any other ever developed for the same class of service. Its application is not limited to the field in which hoists have been generally used, such as ice plants, machine shops, foundries, newspaper offices, etc., but it can be applied wherever handling is to be carried out by overhead means and it offers a high speed, efficient, labor-saving substitute for the chain block in countless fields that have hitherto employed, purely mechanical means.

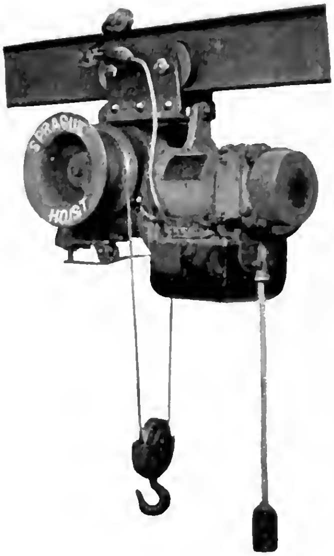

Fig. 36. ½-ton Hoist with Push-button Control

THE MAGNAR BATTERY CHARGER

An improved mechanical rectifier of the vibrating type was developed, particularly for charging storage batteries used in railway signal systems.

Fig. 37. Mechanical Rectifier for Railway Signal Service

In this service storage batteries are used to supply power for the operation of automatic block signals. Separate batteries are required at each signal location and each battery is charged continuously at a very low rate by means of a rectifier. This system is termed "floating charge" or "trickle charge." The charging rate is adjusted to a value which will just compensate for the average discharge of the battery. This rate rarely exceeds one ampere and frequently is as low as one-tenth ampere.

In the new rectifier, Fig. 37, the armature or vibrating reed is tuned magnetically by the flux of a permanent magnet. The armature is provided with a face plate held in tension in the field of the magnet so that by varying this field the frequency of the armature can be changed.

TRANSFORMERS

The renewed activities in hydro-electric development and the expansion of central station equipment resulted in an unprecedented production of transformers of all classes.

Among the large water-cooled type, there were under construction seven 50-cycle, 20,000-kv-a., 220,000 72,000-volt, single-phase units which are larger in their physical dimensions than any transformers of this type previously built.

Among auto transformers, there were eighteen 50-cycle, single-phase units with an output capacity of 17,500 kv-a. each. They are normally rated at 5550 kv-a., 220,000 volts Y or 200,000 volts Y/150,000 volts Y. They are supplied with a tertiary winding for full rated capacity, and are intended for interconnection between the 150,000-volt and 220,000-volt lines of the Southern California Edison Company. An unusual feature of their operation is the fact that they are to be connected in the line without the usual high tension switches or lightning arrester protection.

The activity in the construction of these large high voltage units is indicated by the fact that in 1921, there were eleven 220,000-volt transformers under construction, whereas in 1922 there were thirty-five with a total capacity of about 400,000 kv-a. These figures include construction by both the General Electric Company and other manufacturers.

For use with the 65,000-kv-a. waterwheel generators which will be installed by the Niagara Falls Power Company, there were under construction ten water-cooled, 25-cycle, single-phase, 22,000-kv-a., 68,000Y 12,000-volt transformers. While not exceeding in over-all physical dimensions transformers of this type previously built, they required core and coils which, due to the low frequency at which they will operate, were of record size.

The largest 3-phase water-cooled transformers consisted of eleven 60-cycle, 18,750-kv-a., 102,000 6600-volt units for the Wateree Division of the Southern Power Company. This rating is based on a 40-degree rise but these transformers will have the exceptional continuous rating of approximately 25,000 kv-a.

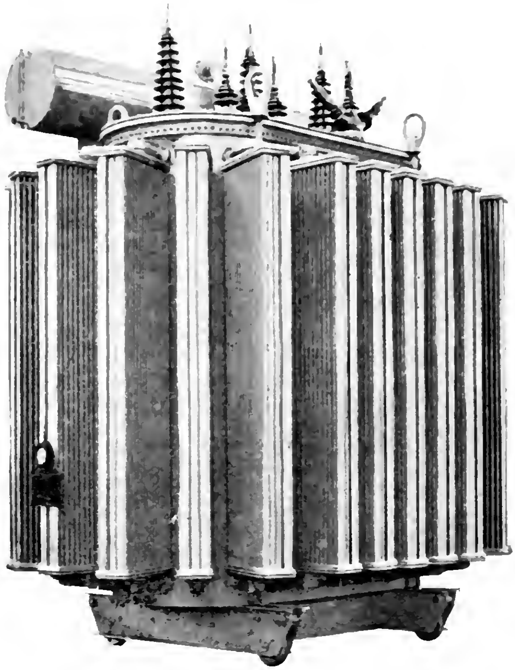

Fig. 38. 12,000-kv-a. Self-cooled Transformer, viewed from low-voltage side

The largest self-cooled, 3-phase transformers, Fig. 38, ever constructed, were completed and shipped during the year. They consist of two 60-cycle, 12,000-kv-a., 44,000-13,600 2300 4000-volt units with a 50 per cent overload capacity for two hours.

These transformers are provided with three windings, Fig. 39, for simultaneous operation, the 44,000-volt winding being designed for 12,000 kv-a., the 13,600-volt winding for 8000 kv-a. and the 4000-volt winding for 4000 kv-a. This gives them an equivalent kv-a. rating greater than any other self-cooled transformer.

The general tendency toward the use of transformers of ever increasing capacity is indicated by the fact that the average size of all types of units produced during 1922 was about 1000 kv-a. greater than the average for 1921. This development is indicated clearly by the figures in Table A, and is more uniform for the self-cooled type than the water-cooled type.

TABLE A
AVERAGE UNIT SIZE OF POWER TRANSFORMERS IN KV-A.

Year	Self Cooled	Water Cooled	All Types
1919........	1175	4325	2150
1920........	1325	3175	2175
1921........	1575	4150	2750
1922........	1700	6000	3750

Another indication of the growth in the average size of transformers is the fact that during 1922 there were more units of 10,000-kv-a. capacity and above, either completed or under construction, than the combined output in excess of 10,000 kv-a. for all previous years.

There was a steady growth in the demand for transformers equipped with oil conservators and a much greater range of sizes and voltages were so furnished than in previous years. The voltage limitations for this equipment were abolished for all units of 2000 kv-a. and above and the conservator was provided in special cases for even smaller capacities. The widespread adoption of this important auxiliary for securing maximum efficiency in the operation of transformers is indicated by the fact that, at the close of the year, there were in service approximately 1000 transformers with an aggregate capacity of about 5,000,000 kv-a. equipped with G-E conservators.

Important advances were made in another modern feature of transformer equipment by the application of ratio adjusters to larger sizes and higher voltages than in previous years. It has now been standardized for current capacities up to 500 amperes and a modified type was provided for four 1250-amp., 13,200-volt units. There were also under construction twenty-two 100-amp., 150,000-volt units each of which will be so equipped.

While the ratio adjuster was originally considered principally as a convenience by operators, its practical utility has been fully demonstrated in the saving of time effected by its use, especially on systems where transformers are utilized on interconnecting lines. This experience has resulted in numerous demands for the ratio adjuster for installation in large power transformers which were installed prior to its development.

There was developed a new system of cooling large oil insulated transformers which must be operated in locations where an adequate supply of cooling water is not available. This system comprises a battery of radiators, installed either on the transformer or in a separate location, and in which the natural flow of oil between the transformer tank and the radiator is accelerated by the external application of low pressure air currents. Piping is run from the source of air supply to the radiator and the air is directed against the radiator sections by numerous small jets. In effect, these small streams of air wash the heat from large areas of the radiator and do it very efficiently with air delivered at only a few ounces pressure, thereby rendering it possible to cool large transformers economically by this method.

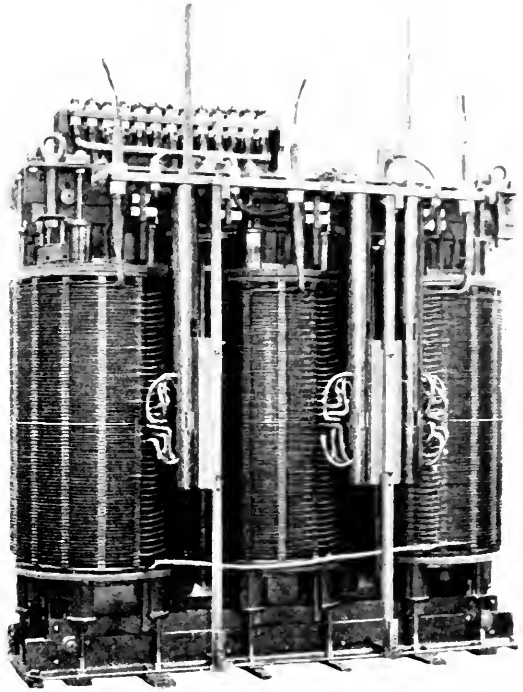

Fig. 39. Coils of 12,000-kv-a. Self-cooled Transformer, viewed from high-voltage side

Another interesting auxiliary device, Fig. 40, for transformer operation consists of an oil drying and purifying outfit which utilizes the principle of the centrifugal separator. The necessary heat is applied electrically and the rotating element is actuated by a geared motor drive, the entire equipment being self-contained and mounted on a truck so as to be readily portable.

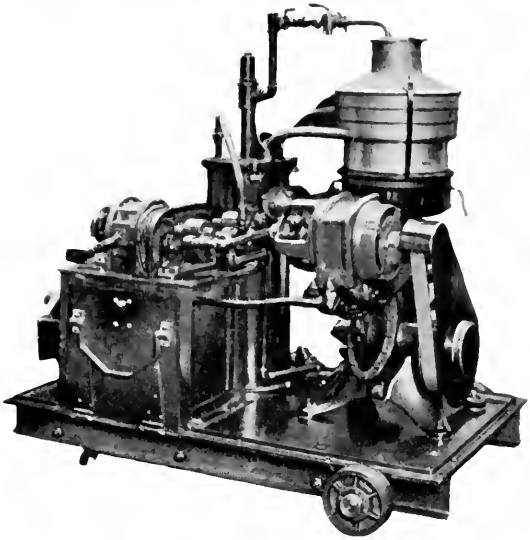

Fig. 40. Centrifugal Oil De-hydrator, capacity 300 gallons per hour

In order to meet a growing demand for reduced weight in distribution transformers designed for pole mounting, a complete new line of welded steel tanks was placed in production for transformers of from 10 kv-a. to 100 kv-a. These tanks are plain, corrugated or tubular, Figs. 41 and 42, and are electrically welded.

MILLION-VOLT TEST

A million-volt, three-phase testing set, Fig. 43, was completed and placed in service in the high voltage engineering laboratory of the Pittsfield Works. A detailed description of this equipment appeared in the last issue of the Review. The design and construction is entirely new and intended expressly for operation at one million volts three-phase with grounded neutral, and one million volts single-phase to ground, although various other connections are possible, and it has actually been operated at 1,200,000 volts single-phase with grounded neutral, and 1,500,000 volts single-phase with ground 500,000 volts from one end, giving arcs up to 14 ft. in length between sharp points.

The spectacular features of this testing set are, however, of less importance than its usefulness in exploring certain fields of pure science which have always been the subject of conjecture, and in aiding in the design, construction and test of electrical apparatus of the highest voltage.

The design is similar to that of standard testing transformers of lower voltages and has many points of resemblance with power transformers, although it contains some unusual features and refinements of detail made necessary by the extreme high voltage and the special requirements of testing and research work.

INDUCTION VOLTAGE REGULATORS

The necessity for extremely close regulation in the operation of induction voltage regulators resulted in the production of a new magnetic type of brake, Fig. 44, which is absolutely noiseless in operation and which insures practically instantaneous stopping of the motor.

The brake consists of a base with two brake arms held in contact with the brake pulley by an adjustable spring. In addition there is provided an angular pull magnet which, when excited, operates a cam and releases the brake pressure on the motor pulley.

The field core for this magnet is assembled in the base casting and is held in place by a clamping screw. This casting also contains the step bearing and bottom aligning bearing for the magnet armature. The upper bearing for the armature is contained in a drawn steel shell which is pressed on over the field core.

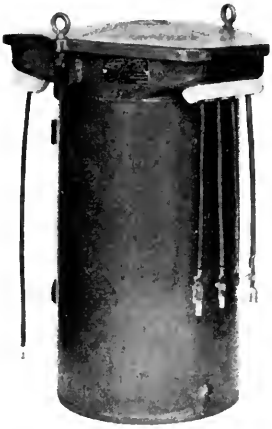

Fig. 41. Plain Welded Steel Tank for Distribution Transformers

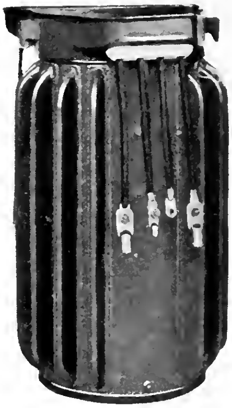

Fig. 42. Corrugated Welded Steel Tank for Distribution Transformers

The upper end of the armature shaft is flattened on opposite sides to form a cam, which operates against two studs on the brake arms to release the brake pressure when the brake winding is excited. These studs are threaded and provided with lock nuts so that they may be adjusted to compensate for wear of the brake shoes.

Just below the cam on the brake armature shaft is a knurled collar by which the armature may be turned through an angle of 90 deg. in which position the cam will hold the brake open to permit operation of the regulator by hand.

X-RAY TUBES

A new high voltage, high power X-ray tube was produced for deep therapy which operates on 200,000 volts, at 8 milliamperes. This represents a considerable advance in voltage for X-ray tube operation.

The new tube has already been utilized industrially as well as for therapeutic work and is now in commercial production.

THE MAGNETRON

The largest vacuum tube ever made consists essentially of a water-cooled cylindrical anode 30 in. long and 1¾ in. in diameter. In the axis of the anode is a tungsten filament 0.4 in. in diameter and 22 in. long. This filament is excited by current of 1800 amp. at 10,000 cycles, the filament excitation requiring about 20 kw. The electron current to the cathode is interrupted 20,000 times per second. By the use of properly tuned circuits this can be used for the production of high frequency power for radio or any other purpose.

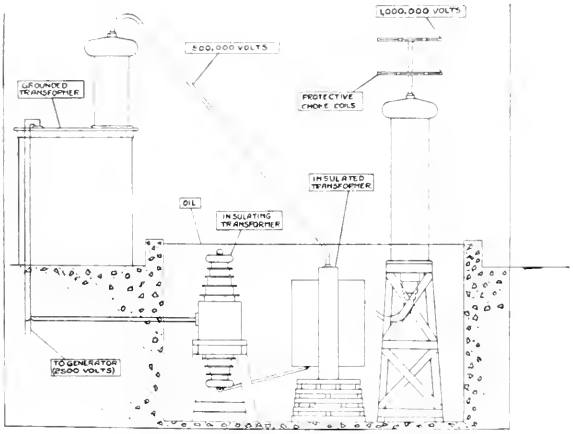

Fig. 43. General Arrangement of Million-volt Testing Set

This particular type of tube, which is called the Magnetron, Fig. 45, will supply 1000 kw. of 20,000-cycle power at an efficiency of 70 per cent, operating with an anode potential of 20,000 volts direct current.

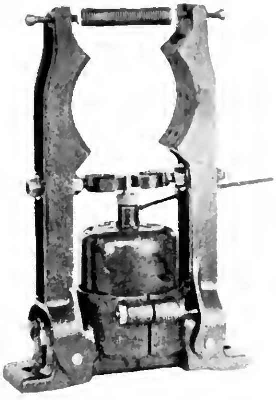

Fig. 44. Magnetic Brake for Induction Regulator

PALLOPHOTOPHONE

A new method of recording and reproducing sound was developed, which is a distinct improvement in many ways over all previous methods used and opens up several entirely new fields of application.

There are two distinct devices in the Pallophotophone, Fig. 46, one for recording and one for reproducing the sound, and either may be used independently.

The recording device consists essentially of a tiny mirror on which is reflected a beam of light. This mirror is attached to a delicately adjusted vibrating diaphragm and when sound waves cause the diaphragm to vibrate, the mirror oscillates and the ray of light causes the projection of corresponding oscillations upon a strip of photographic film which passes in front of the mirror in a continuous motion.

The film is then developed in the usual way and shows a succession of delicate dark markings which constitute the sound record.

In the reproducing device, the film passes in front of an arrangement of vacuum tubes which are sensitive to light so that the variations in the light falling on them, caused by the lines recorded on the film, produce electromotive force variations in the circuit in which they are connected. Therefore, as the film is moved in this device, an electric current is created which corresponds with great accuracy to the original sound wave. This electric current can be made to actuate a telephone, loud speaker or to operate radio broadcasting apparatus directly.

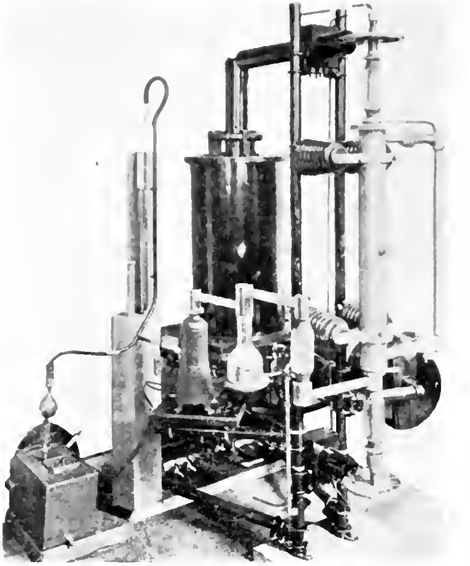

Fig. 45. 1000-kw. Vacuum Tube

Many interesting applications of this new device have already been made and a few possibilities can be briefly outlined as follows.

It makes possible the talking motion picture, for on a film of the normal width, both sound and action can be recorded simultaneously and projected in absolute synchronism. It is practically unlimited as to the length of record it can make and reproduce and is, therefore, suitable for recording speeches, debates, concert programs, in the taking of evidence and for any purpose where a lengthy record of sound is required. It can be duplicated and used as a film phonograph and applied in radio telegraphy, in producing wireless signals and for audio amplification. It has already been successfully applied in radio broadcasting.

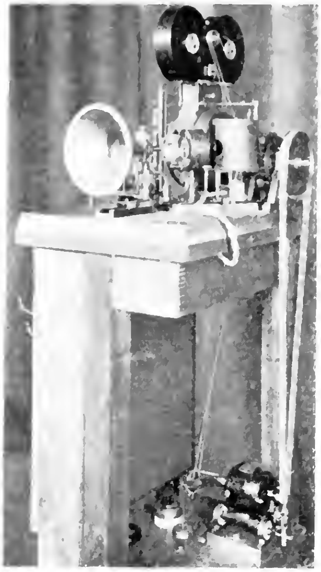

Fig. 46. The Pallophotophone

RADIO

Important progress was made in the design and manufacture of radio telephone and telegraph apparatus, both for commercial and amateur purposes. The sale of amateur equipment made a spectacular increase, due to the suddenly aroused interest of the public in the new application of radio to broadcasting.

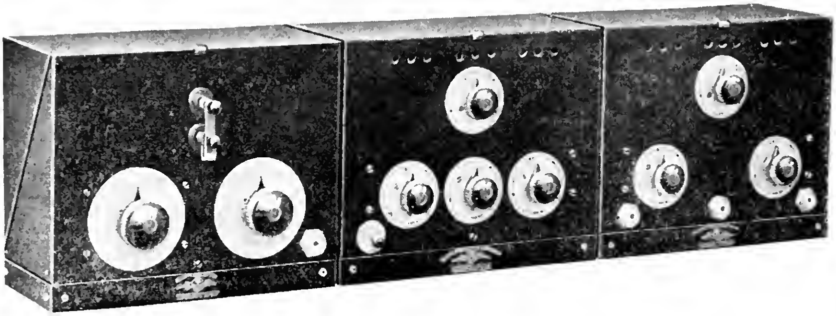

Fig. 47. Radio Receiver, Frequency Amplifier, and Detector Amplifier

The line of standardized component parts which had been originally designed for commercial purposes was later produced for the amateur. Broadcast receivers were built, making use of these parts and a line of sectional units, Fig. 47, such as the tuning unit, the 3-stage radio frequency amplifier unit and the detector-amplifier unit, was developed. The main idea in these sets was the production of receivers, each of which would serve a definite function separately, and could also be easily combined.

One of the interesting applications of broadcast receiving was the installation aboard several Pullman trains of equipment, Figs. 48 and 49, for entertaining the passengers with concerts throughout their journey, and to keep them informed on such topics as weather, market and stock reports.

Fig. 48. Antenna Construction on Pullman train for radio reception en route

In the line of commercial equipments, new requirements were met, due in many cases to broadcasting. In one case, a power company sought a duplex radio telephone installation with which it could provide, during times of storm, against possible interruption of communication between several of its stations 75 miles apart. At the same time, signals from nearby broadcasting stations operating on 360 meters were not to interfere with operation of this station on the only available wavelength of 400 meters. The set was to be operated through remote control from a desk stand by the regular power house switchboard operators and to require no attention except that usually given to such moving parts as motors and generators. This set was installed and is operating successfully.

Fig. 49. Radio Broadcast Receiver Installation on Pullman train

For the use of amateurs and for installation on small boats and yachts there was produced a small radio telephone transmitter, Fig. 50, having an output of 20 watts in the antenna. It is built so that it can be operated either from a motor-generator set or from a kenotron rectifier which was designed for this equipment. It can also be used on telegraph transmitter either continuous wave or interrupted continuous wave.

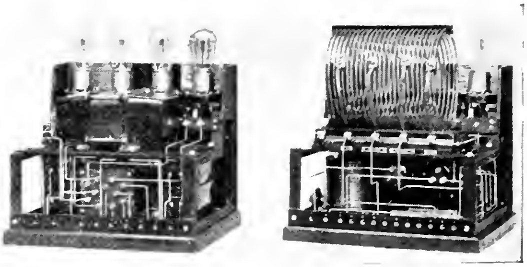

Fig. 50. Kenotron Rectifier and back view of Radio Transmitter

A new tube attachment for converting spark transmitters into vacuum tube continuous wave transmitters, makes it possible for owners of spark sets to realize the advantages of continuous wave transmission at a minimum cost. It has an output in the antenna of approximately ½ kw. continuous wave and a wavelength range of from 2000 to 2400 meters. It utilizes the power equipment and high potential transformer of the spark transmitter and includes necessary switching apparatus so that communication can be transferred from the spark set to the tube attachment.

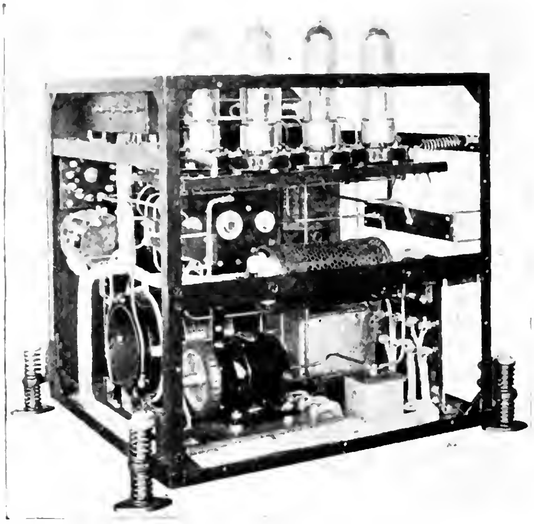

Fig. 51. Aircraft Radio Transmitter

This equipment, Fig. 52, makes it possible not only to carry on communication with stations now listening-in on 2200 meters, but to carry on communication over much greater ranges with a 2-kw. spark transmitter. During actual service tests conducted with one of these transmitters, a range of 1500 miles daylight, over water, was realized.

An aircraft transmitter was constructed for telegraph communication only with a continuous wave output in the antenna of 300 watts. Provision was also made for interrupted continuous wave telegraphy. The transmitter, Fig. 51, was designed to operate from a double current stream line generator driven by an automatic speed regulating propeller.

Two telegraph transmitters having outputs of 2 and 4 kw. respectively into the antenna were produced for installation in Mexico. They were the first sets to include the method of construction which has now been adopted as standard for medium power tube transmitters, and were a radical departure from vacuum tube transmitters previously built.

Each equipment, Fig. 53, includes a kenotron rectifier which supplies the necessary high voltage direct current for the plate supply of the oscillator unit and a so-called "tank circuit" by means of which the transmitted wavelength is kept particularly constant and free from undesirable harmonics.

A number of telephone and telegraph transmitters were built for installation on submarines of the U. S. Navy, which include many novel features of construction and operation. They are designed for transmitting either on the flat top antenna or a loop and include a break-in system whereby the operator can listen-in between dots and dashes of the transmitted message; they are available for three methods of communication and have an output of 600 watts continuous wave in the antenna. The complete equipment, Fig. 54, is extremely restricted in dimensions on account of the service for which it was built.

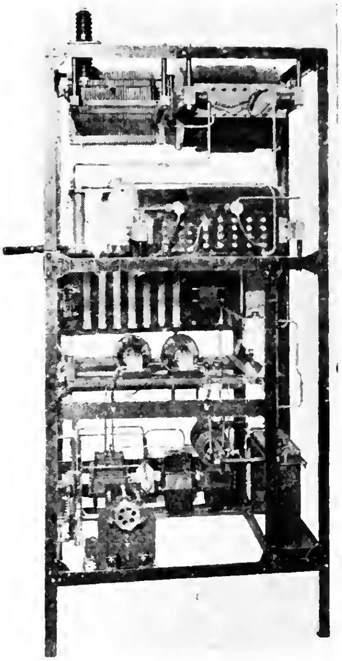

Fig. 52. Vacuum Tube Radio Transmitting Equipment for use in connection with spark sets

New apparatus designed and manufactured for use with 200-kw. Alexanderson alternator equipments consisted of antenna tuning inductances, remotely controlled antenna wavechange switches and remotely controlled antenna variometers.

In the operation of remotely controlled antenna variometers* for indoor service, means for remote control from switchboard and hand control at the variometer were provided.

These variometers are connected in series with 200-kw. Alexanderson alternators, feeding energy to multiple tuned antennae. They are used to maintain close adjustment of antenna tuning, particularly when antenna capacity is varied by wind and sleet. Porcelain supports are used throughout for all parts connected in circuit and the conductor is composed of 4270 strands of five mil copper wire, each strand insulated with enamel. Varnished cambric and treated braid form the outside insulation.

Due to the high-intensity high-frequency electro-magnetic field produced by the windings, no metals of any kind are used inside the windings. The top supports of the framework are of brass. Iron pipes attained high temperatures at fractional load in the windings. Closed circuits in the pipe framework are broken up by suitable insulators to prevent circulating currents.

The stationary and movable windings may be connected in series or parallel. The average range of inductances in series connection is 0.19 to 1.1 milli-henries. The maximum coupling averages 50 per cent.

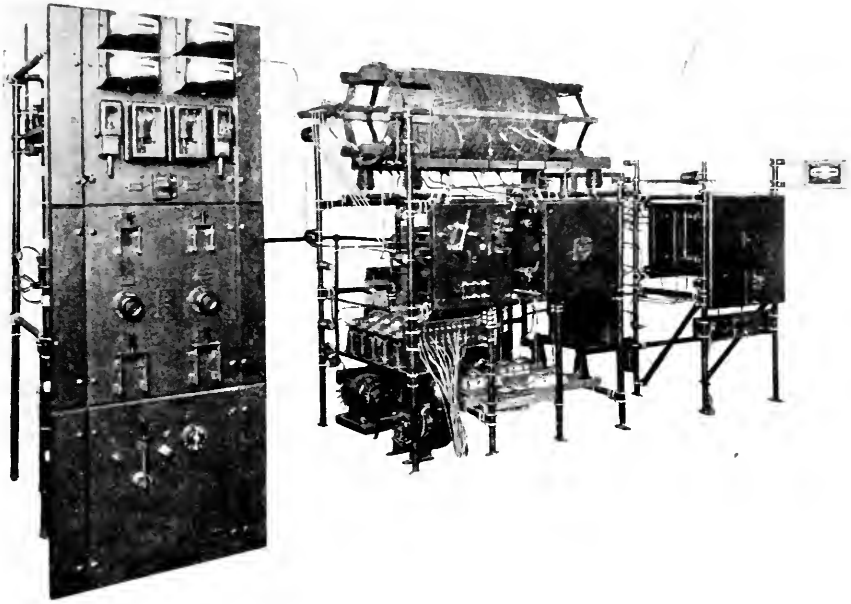

Fig. 53. Four-kilowatt Vacuum Tube Radio Transmitting Equipment

CARRIER CURRENT

Complete carrier current equipment for telephone communication over the high tension transmission lines of power companies was developed and a number of sets were installed.

The transmitter has an output of 50 watts and is rated at 75 miles, providing there are not a great number of tie-ins or transformer stations in this distance. The equipment, Fig. 55, includes a calling system whereby a bell is rung at the station called when the station calling actuates a push button on a desk stand forming part of the equipment.

SWITCHING APPARATUS

A new line of oil circuit breakers was produced for indoor and outdoor service, the design of which was based on that of the 220,000-volt breaker furnished to the

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* A variometer of this type is illustrated on the cover of this ssue of the REVIEW.

Southern California Edison Company. These breakers are for heavier interrupting capacity service than any previously constructed. They have round tanks, and are designed to be entirely tight and non-oil throwing, are provided with explosion chambers, Fig. 56, and separating chambers, and have an internal operating mechanism. By internal mechanism is meant the placing of the mechanism underneath the cover of the breaker. Units of this type for voltages from 7500 to 220,000 were constructed but the line has not yet been completely developed.

Fig. 54. Vacuum Tube Transmitter and Power Panel for use on Submarines

The largest unit, Fig. 57, so far constructed has a rated carrying capacity of 600 amperes at 220,000 volts and an interrupting capacity of 1,500,000 kv-a. Breakers of 800- and 1200-ampere capacities for 73,000 volts were also produced with interrupting capacities up to 1,000,000 kv-a.

The main contacts of the 800- and 1200-ampere sizes, Fig. 58, consist of stationary copper brushes making contact on a movable blade which is mounted on the wooden operating rod. The plunger type contacts consist of copper rods fastened to the blade, or bridging member. These plungers make contact with a set of segmental contacts mounted in the upper end of the explosion chamber. An adapter is fastened to the bottom of the bushing and a contact retainer is threaded into the base of the adapter. The explosion chamber is bolted to the adapter.

Motor operated breakers, Fig. 59, were redesigned to make them oil tight and explosion proof. That is, the throwing of oil was entirely eliminated as well as the danger of secondary explosion of the gas in the oil tank above the oil.

These results were accomplished by an oil and gas tight cap on the oil vessel, a stuffing box in the upper insulators around the contact rods, and "Separating Chambers," Fig. 60, leading from the top of the oil tank.

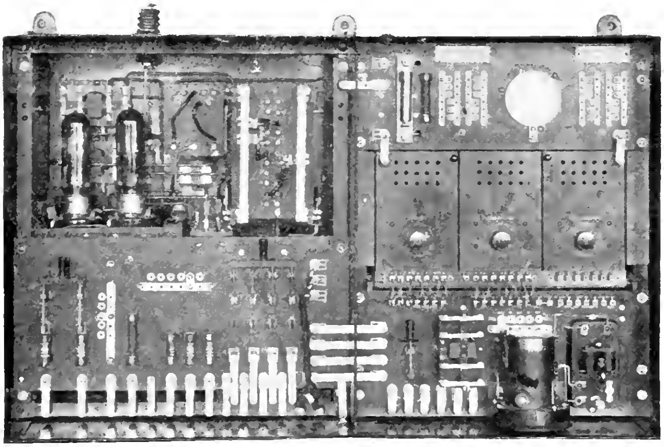

Fig. 55. Transmitter Receiver for 50-watt Carrier-current Telephone

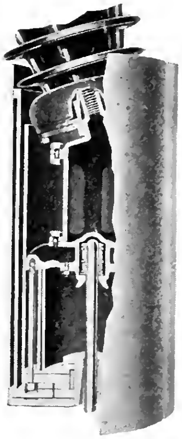

Fig. 56. Cross Section of Explosion Chamber for 220,000-volt Oil Circuit Breaker

When the breaker is opened under load the arc is interrupted in the lower part of the oil tank. The gas that is generated passes upward, mixed with some oil, through the center hole in the lower baffle and the gas and oil are partially separated while passing through the upper baffles. They are finally carried to the separating chamber where complete separation of the gas and oil and cooling of the gas take place. The oil then returns to the tank.

From the separating chambers the gas is carried through a system of communicating pipes to a general outlet. This outlet should be connected to a switch house header which should be piped away so that the gas will not be liberated in the switch house.

A new type of oil circuit breaker was designed for use on constant current transformer panels for series lighting, where oil circuit breakers are desired in place of the standard plug switches.

This circuit breaker meets the requirements of a small interrupting capacity breaker and is available for non-automatic operation only. It is manufactured in two varieties: a double-pole single-throw breaker for either the primary or the secondary side of the constant current transformer; and a double-pole single-throw breaker, Fig. 61, with an additional blade for short-circuiting the lighting circuit, that is, in this form the

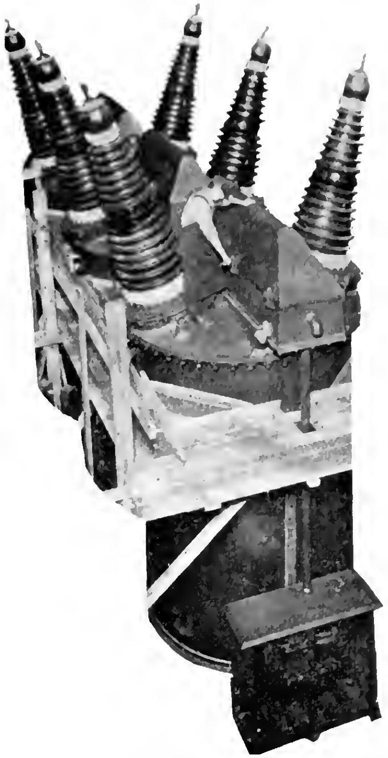

Fig. 57. View showing Physical Size of the Largest 220,000-volt Oil Circuit Breaker

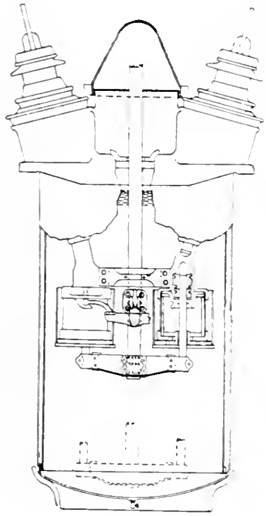

Fig. 58. Internal Arrangement of 800-amp., 73,000-volt Oil Circuit Breaker

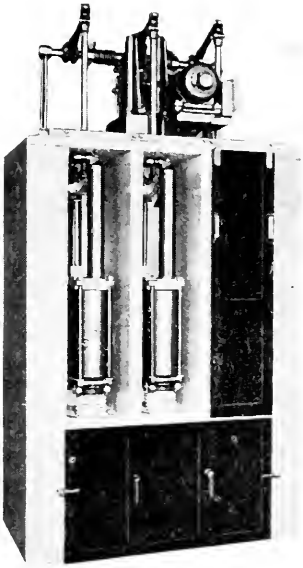

Fig. 59. Old-type Explosion-proof Motor-operated Oil Circuit Breaker

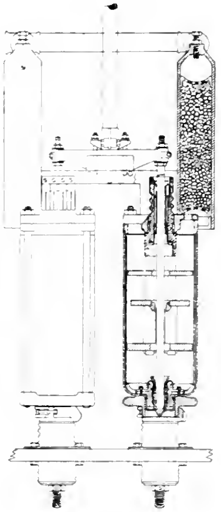

Fig. 60. Arrangement of Oil Tanks and Separating Chambers

breaker performs the same duty as one short-circuiting and two open-circuiting plug switches.

When the breaker is used on the primary side of a transformer, it is necessary to use fuses for overload protection.

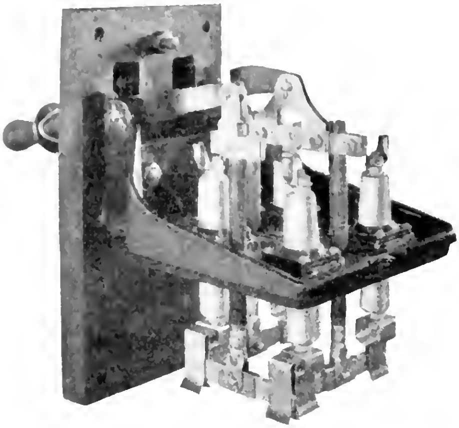

Fig. 61. Oil Circuit Breaker with Short Circuiting Switch, Double-pole, Single-throw

The large cell-mounted motor-operated central station oil circuit breakers, the oil tanks of which are electrically dead, were adapted to the so-called isolated phase arrangement. That is all breaker poles, disconnecting switches and bus work for any particular phase are installed in a cell structure isolated from each of the other phases.

Two detailed schemes of phase separation were worked out, namely, the horizontal separation and the vertical separation. In the horizontal method of separation, the breakers of all three phases may be on the same floor but each pole of any phase is separated from any pole of any other phase by a considerable distance.

In the vertical method of separation, each pole of any phase, and the bus for that phase, is located on a separate floor and the operating mechanism is on a floor above or below.

The paralleling mechanism for these circuit breakers may be placed between the two oil vessels of each pole and forms part of the breaker unit so that it is not necessary to install and set up a separate paralleling mechanism. This is particularly advantageous where isolated phase arrangements are involved.

A motor-driven centrifugal device, Fig. 62, was developed for closing circuit breakers. It makes use of centrifugal force in a manner similar to that of a governor on a steam engine and will close any circuit breaker or combination of breakers now using the standard universal lever for manual operation.

Although primarily designed for operation by alternating current, the motor on this device may be either for alternating or direct current. The device with the alternating current motor is particularly adapted to the operation of breakers in sections where no direct current is available and to automatic stations where alternating current is available and automatic reclosing is desired.

The motor revolves a pair of weights attached to the motor shaft, thereby developing a centrifugal force which tends to throw the weights outward and causes the operating mechanism to close the breaker.

Current is thrown on the motor either by a control switch or a relay. The breaker may be tripped by hand, by a control switch, or a relay and provision is made for mounting from one to four a-c. or d-c. trip coils as required.

Four tower arrangements were adopted and standardized for small outdoor stations ranging in capacities from 300 to 3,000 kv-a., 13,200 to 50,000 volts, but the same tower is used in each case; the only difference being the size and location of the steel bracket which supports the low tension busses.

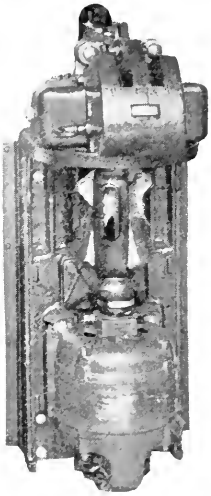

Fig. 62. Motor-operated Centrifugal Circuit Breaker Closing Device

Outdoor switch houses, Fig. 63, were provided with panels equipped with automatic reclosing equipment.

In many cases outdoor sub-stations are located in isolated places and in case of overload on the low tension feeder which trips out the oil circuit breaker, it would be necessary to reclose it by hand. To overcome this, an a-c. reclosing oil circuit breaker is used. This means a standard outdoor switch house with the addition of notching and reclosing relay and a-c. single-phase, 220-volt motor-operated mechanism for controlling the oil circuit breaker.

When the oil circuit breaker trips out on an overload, Fig. 64, the reclosing relay will reclose the breaker after an interval of from 5 to 30 seconds. If the overload has been cleared the breaker will remain closed. Should the overload still persist, it will again trip out and close after another interval of from 5 to 30 seconds. Should the overload still be on the line, the oil circuit breaker will trip out for the third time and remain open and locked out until manually reclosed and reset.

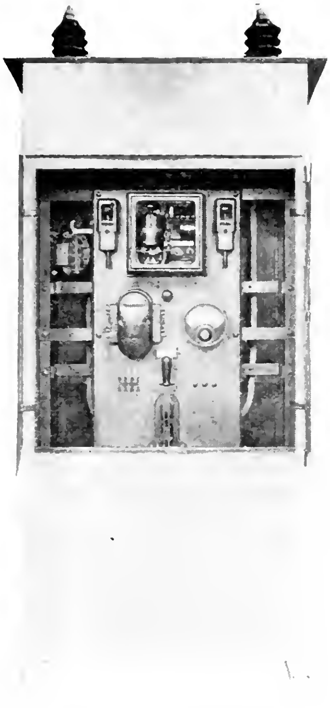

Fig. 63. Outdoor Switch House, 6600 volts
50 amp., 3 phase, 60 cycles

The development of this automatic reclosing alternating-current equipment has made economically feasible the supplying of alternating-current energy to small, isolated communities.

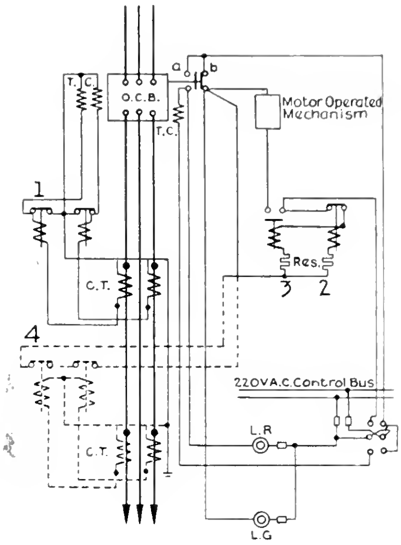

Fig. 64. Automatic Reclosing and Metering Equipment

(1) Alternating-current feeder overload time delay relay
(2) Alternating-current feeder notching relay
(3) Alternating-current feeder reclosing relay
(4) Alternating-current feeder locking-out relay

Truck type panels were changed from knockdown to permanent unit housing which is completely assembled into a rectangular cabinet with welded joints. Disconnecting devices are so assembled and adjusted that they bear a permanent relation to the tracks on which depend the interchangeability of the trucks.

A standard line of these switching units, Fig. 65, includes feeder, generator, motor and bus section panels and circuit breakers for potentials up to and including 15,000 volts. For circuits up to 7500 volts the busses are mounted on the disconnecting device supports at the rear of the housing. Above this voltage they are mounted in a superstructure so that a uniform depth of housing may be maintained for all voltages.

Where it is desirable, it is now feasible to use steel panels instead of slate panels, thereby eliminating the possibility of breakage and making it possible to ship assembled units which can be readily bolted together when received at the point of installation.

Insulated rod heavy duty bus supports, Fig. 66, were designed for use on low potential circuits up to 3500 volts alternating or direct current, and up to 10,000 amperes.

The construction comprises 1¼-in. pipe encased in cylindrical insulators which enables it to withstand high tensile and torsional strains and the cantilever strength of the support is insured by anchoring the top and bottom of the insulated rods. Standard top and bottom fittings are used so that the supports may be pipe mounted and bolted to either a beam or bracket.

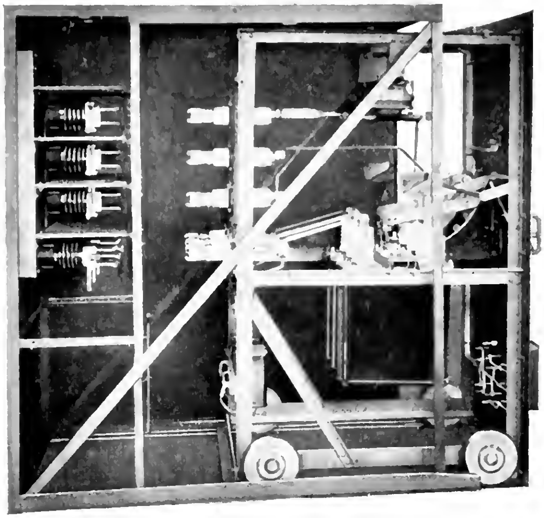
Fig. 65. Mechanism of Improved Truck-type Panel

The busbar clamps are made to support 2- and 4-in. busbars and require only two bolts. These clamps are so designed that when mounted on the insulated rod they are at a sufficient angle to give easy access for bolting together. This arrangement lends itself readily to the use of tier bus construction for minimizing heating in the conductors.

Relays

The application of relay protection was extended to the protection of three-phase power cables against internal short circuits or short circuits to ground. This was accomplished by the combination of single-phase and polyphase directional relays.

The potential transformers used for the excitation of the potential coils of the directional relays are connected Y—delta instead of delta—delta as is customary. The potential coil of the single-phase directional relay is connected across an opening in the delta on the secondary side of the potential transformers, the potential coil of the polyphase relay is connected across the secondaries of the potential transformers as usual. In this scheme care must be taken in the selection of the potential transformers so that the ratio of transformation will make 110 volts available across the secondary coils.

A sheath transformer is wound about the cable and connected to the current coil of the single-phase directional relay while current transformers in each phase supply the excitation for the polyphase relay.

In normal operation there will be no potential nor current impressed upon the single-phase relay nor will there be any operation of the polyphase relay. Should a fault develop in the cable, either between phases or to ground, the excess current flowing in the faulty member will induce a current in the sheath transformer supplying the single-phase relay and the fault will also be reflected by a potential across the open secondary delta, the direction of current flowing therefrom being determined by the location of the faulty leg or phase.

The standard induction type overload relay, Fig. 67, was improved and simplified. The saturating transformer was omitted and a single coil of edgewise wound copper now replaces the several windings previously used.

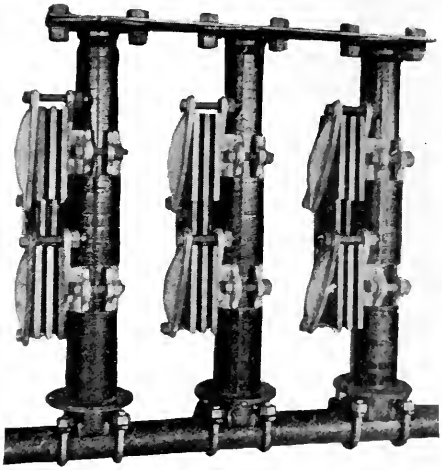
Fig. 66. Insulated Rod-type Busbar Support for Heavy Duty 3500 volts up to 10,000 amp.

This relay is capable of carrying continuously the current required for operating at any tap setting.

Electrical clearances were increased in a number of cases and more accurate current adjustment is now possible. This adjustment can be made from the front of the panel without disturbing the relay.

Fig. 67. Improved Induction Type Relay

A new induction overload relay, Fig. 68, was produced for use in circuits where the available current for tripping is very small, and where sensitiveness is desired without the use of current transformers. The capacity of its coil is one ampere and the relay must be used with the bushing transformer with which it is calibrated.

Fig. 69. Induction Polyphase Power Relay with Two Driving Elements

A relay was designed for reverse polarity service and also operates on under voltage. It is sensitive, having its movable armature, which actuates the relay contacts, and its potential coil lying in the field of a strong permanent magnet. Loss of excitation of the potential coil or excitation with reverse polarity will cause the contacts to open. Calibration adjustment is made by the movement of a calibrating lever which changes the tension of a spring attached to the movable armature.

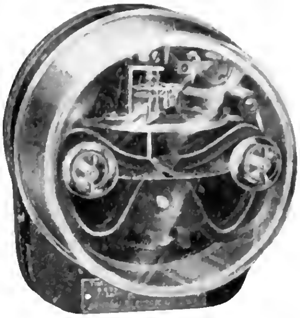

Fig. 68. Induction Overload Relay for Low Currents

A new relay of the induction type was produced, similar in appearance to an induction watthour meter, and is used to indicate when load conditions exceed or fall below a predetermined value.

These relays, Fig. 69, are provided with two separate driving elements each element having a current and a potential coil which drive two disks mounted on a single vertical shaft. The shaft controls the operation of a set of double throw contacts which energize the coils of an auxiliary relay on over power and short circuit this coil on under power, thereby quickly and automatically relieving the main contacts of the relay of the burden of the circuit breaker tripping current by the use of the heavier contacts of the auxiliary relay which close instantaneously and remain closed as long as the tripping current flows.

An induction type balanced current relay was designed to give differential protection to delta connected machines when differential protection cannot be obtained in the usual manner. It is made with three elements each consisting of two magnets between which a disk revolves. The coil of one magnet, called the restraining coil, in each element is connected in one phase and exerts enough pull on the disk to hold the disk against a stop unless the pull of the other coil which is normally weaker, called the operating coil, and which is connected in another phase, is sufficient upon unbalanced loading to overcome the pull of the restraining coil when the relay functions to trip the circuit breaker.

An interesting addition to a standard unit instantaneous overload relay consists of an indicating semaphore vane, Fig. 70, by which the faulty circuit is readily detected after the operation of the relay. This relay is used to open the trip circuit of a feeder circuit breaker when the overload exceeds the interrupting capacity of the feeder circuit breaker, and thereby prevent the opening of the feeder breaker. The fault must then be cleared by a larger circuit breaker at a point nearer that of generation. Where a number of relays are used the semaphore indication is especially valuable.

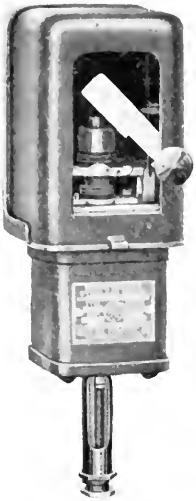

Fig. 70. Overload Relay with Indicating Semaphore

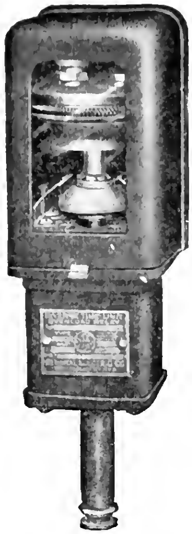

Fig. 71. Inverse Time Delay Circuit Closing Overload Relay

A standard unit overload relay, Fig. 71, was provided with circuit opening and circuit closing contacts for controlling two circuits and can be used either for instantaneous or time delay operation. The arrangement of the fixed contacts provides for very flexible application and they may be changed by reversing the contacts to make the relay either circuit opening or circuit closing for controlling up to three circuits.

Another standard relay was provided with a notching lockout device to allow the circuit breaker to be closed a definite number of times on overload, within a given time, after which the circuit of the circuit breaker closing device is interrupted and locked open until the relay has been manually reset. The notching device can be adjusted to permit reclosing the circuit breaker one, two or three times before it is locked out of service.

A potential auxiliary multi-contact relay, Fig. 72, was arranged for controlling ten circuits, nine of which are closed and one opened by the energizing of the relay coil.

It is applicable for use with other relays for machine protection when it is desirable to perform a number of separate functions at the same time. In the protection of synchronous generators it is often desirable to open two or more main circuit breakers, one or more field switches, operate a bell alarm circuit and perform other special functions. By using this relay for such applications the control wiring may be materially simplified.

Normally the relay contacts are held in place by a latch which is tripped upon operation of the relay and the contacts are rotated through an angle of 90 deg. from which latter position they must be manually reset to restore normal circuit conditions.

The circuit opening contacts are capable of opening the relay coil circuit, making the use of an auxiliary switch unnecessary with this device.

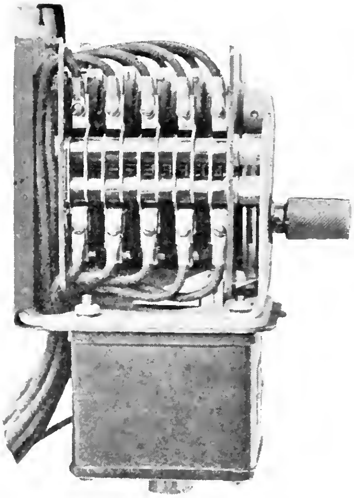

Fig. 72. Auxiliary Multi-contact Relay with Hand Reset

LIGHTING

The estimated sales of tungsten filament lamps (excluding miniature, such as flashlight and automobile lamps) in the United States during 1922 were 205 million lamps. This is the greatest number of tungsten filament lamps ever sold in any year, Fig. 73, the previous record being in 1920, when 202 millions were sold. In 1921 the sales were 160 millions.

The estimated carbon lamp sales in 1922 were four millions; these lamps, therefore, represent less than 2 per cent of the total In 1907 the carbon lamp sales reached their maximum of 63 millions which was the year the tungsten lamp was first put on the market. Ever since that time the percentage and actual number of carbon lamps has decreased each year. If this rate of decline continues, as it probably will, the carbon lamp will soon be a thing of the past.

As it never has been possible to make carbon lamps to an exact predetermined voltage, many central stations, in the early years of the industry, co-operated with lamp manufacturers in adjusting their circuit voltage to something other than the then popular 110 volts. A demand was thus created for lamps for individual voltages between 100 and 130. It became possible with the drawn tungsten filament lamp exactly to predetermine its voltage, and as the demand for carbon lamps rapidly declined, a movement, backed by all the electrical associations, was started in 1913 to reduce the number of lamp voltages to three standards: 110, 115 and 120. During the year 1922, about 90 per cent of the 100-130-volt lamps were of the three standards compared with 45 per cent in 1913. This has been accomplished by central stations gradually raising their circuit voltage to a standard as is indicated by the fact that in 1913 the average lamp voltage was 112.9 and in 1922 about 114.5. The odd voltage lamps sold in 1922, about 10 per cent of the 100-130-volt range, cover mostly 112- and 125-volt lamps, about evenly divided.

While it is probably impractical in most cases to reduce 125-volt circuits to 120 volts, there is little excuse for the use of 112-volt lamps. Lamps labeled 110 volts should be used in their place as the continuation of the early practice, when tungsten lamps were fragile, of using 112-volt lamps on 110-volt circuits to obtain longer life, is no longer desirable with the present-day Mazda lamp, for it is done at a sacrifice of both candle-power and efficiency.

The most spectacular feature of incandescent lamp manufacture was the production of a 30,000-watt unit, Fig. 74, having a capacity of about 60,000 mean spherical candle-power; the largest lamp of its kind ever manufactured. It has a bulb 12 inches in diameter and $18\frac{1}{2}$ inches high and the filament is made of tungsten wire, $^1/_{10}$ inch in diameter and 93 inches long, constructed in four coils. This wire, if drawn into filament wire of the size used in the 25-watt lamp, would supply filaments for about 55,000 such lamps.

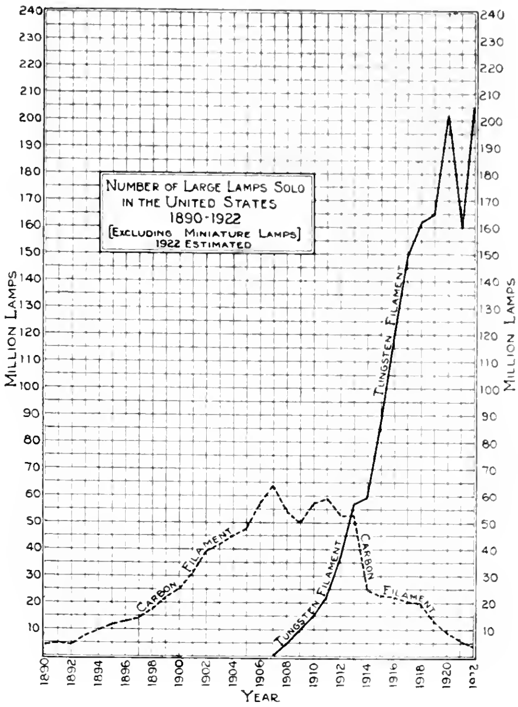

Fig. 73. Number of Large Lamps Sold in the United States 1890-1922 (excluding miniature lamps)

The lamp is gas filled and operates on a 120-volt circuit, consuming 250 amperes. Its use up to the present time has been confined to experimental motion picture work and it has not yet been developed on a commercial basis.

The popularity of the 50-watt white Mazda lamp together with the need of a similar lamp of a higher wattage resulted in the standardization of a 75-watt white Mazda lamp.

Miniature Lamps

Considered only as a part of the incandescent lamp industry of the country the position occupied by miniature lamps does not seem very prominent. If viewed, however, as a separate industry, the figures are impressive as there is every indication that approximately 83,000,000 miniature lamps were used during 1922.

It is interesting to note the trend of this branch of the industry from its beginning. Originally, manufacture consisted principally of flashlight lamps, then considered only as novelties; the subsequent development of automobile lighting brought about a condition wherein the greater proportion of the lamps are now used in that service. Of the total quantity produced over 58,000,000 were of distinctly automobile types.

Fig. 74. 10-kw., 30-kw. and 25-watt Incandescent Lamps

However, it must not be thought that the flashlight industry has not developed during this same period. The consumption of flashlight lamps during the year amounted to practically 16,000,000 lamps. At the time when flashlights were first considered commercially, the lamps required were only a few hundred thousands.

Besides automobile lighting and flashlight service there were other miscellaneous services which required nearly 9,000,000 lamps. Of these practically all were for Christmas tree lighting outfits which required slightly over 8,000,000 lamps.

There was a considerable increase in the application of small incandescent electric lamps to railway signals. These lamps are the 3.5-volt, 0.3-ampere type, operated from four cells of primary battery, and also the 13.5-volt, 0.25-ampere type operated from sixteen cells of primary battery. In the former case the battery is used to light the lamp alone; in the latter case the battery is also used to operate the motors which raise the semaphore arms.

The lamps are used on what is known as "approach lighting" systems; that is, through track relays they light up on the approach of a train, and are extinguished when the train passes the signal. This is done in order to conserve battery energy. Further conservation has been recently secured by the application of electric sun valves similar to those used in the lighthouse service. These valves automatically turn on the current on the approach of darkness, and shut it off when daylight comes.

One very great advantage of the incandescent lamp over the oil lamp which it is replacing in railway signal service is the fact that the oil lamp had to be refilled and cleaned at least every five days, whereas the incandescent electric lamp outfits have been run as long as a year without attention. This means a very great saving in labor.

There was also under development small transformers to operate these lamps where power circuits are available.

Some application of the same type of lamps and batteries was made to small range lights and buoy lights in the lighthouse service. Certain lenses previously equipped with oil and acetylene lamps were used with incandescent electric lamps, and tests have shown that the effective range of the incandescent lamp is materially greater than that of the acetylene or oil flame of equal candle-power.

In the case of the lighthouse service lamps, they are operated from a little electromagnetic flasher which causes the lamps to flash at any desired period. This flasher is so constructed as to consume very little battery energy.

The advantage of these electric lights over the oil light and acetylene light is that they do not need nearly so frequent attention as was the case with the previous lights. Furthermore, battery renewals can be handled in a very much smaller boat, and with less labor than was required to handle the large, heavy tanks of compressed gas previously used.

Incandescent lamps were also more generally utilized for highway crossing beacons. Tests have shown that a flashing red light is very much more effective than a fixed light. In the case of highway crossing beacons, the lamps are being operated by batteries, and also by regular lighting circuits. In some cases where these flashing beacons are used at railroad grade crossings, they are operated by a storage battery, which, in turn, is charged by a primary battery, thus insuring the maximum reliability. In these cases, 6-volt, 40-watt lamps are being used, making an exceedingly conspicuous signal both by day and by night.

The success of light signals on railroads and in the handling of vehicular traffic on thoroughfares led to the demand for standardization of light signals throughout the country. At the request of the various safety and other organizations, the American Engineering Standards Committee appointed a sectional committee to undertake the problem of directing this standardization.

Lighting Practice

In the lighting of a large number of small stores investigation showed that, within a decade, the popular type of luminaire or fixture had changed from the open glass reflector to the enclosing globe. A corresponding tendency was noted in the lighting of other classes of interiors.

Recently the styles in enclosing globes themselves have been changing so that now flat or squat shapes are becoming more and more common, Fig. 75. These tend to direct a relatively large proportion of the light in angles approaching the vertical and less light in those approaching the horizontal. This characteristic of distribution is advantageous, both on account of the better utilization of light and the reduction in glare.

There was a marked tendency prior to 1922, in luminaire design for home lighting, toward those styles which use candelabra and round bulb Mazda lamps, oftentimes without shades or external glassware. During the past year, there were indications of reaction, and an increasing number of luminaires were being equipped with shades and globes. Moreover, there appeared a number of types of special shading devices arranged for attaching to candle fixtures.

The annual fixture market is becoming more and more influential in directing styles in luminaire design. The market held in Milwaukee in the spring of 1922 was made the occasion for an extensive course in lighting practice, which should be influential in promoting proper applications of illumination, especially in connection with fixture design.

Portable luminaires, in the form of table and floor lamps, are becoming more and more popular in home lighting. Some of these have been made so as to direct light to the ceiling for the general illumination of the room. A new type of semi-indirect portable, Fig. 76, was put on the market which bids fair to further popularize the portable luminaire and improve the lighting of homes.

Fig. 75. A typical recent type of luminaire with globe so shaped as to direct as much light as practicable downward and upward rather than horizontally

One of the most hopeful signs of improvement in home lighting was the issuance of a code on luminaire design, prepared by illuminating engineers in co-operation with fixture designers.

Extensive investigations of show window lighting in Cleveland, Ohio, and Newark, N. J., definitely indicated the value of strong illumination, as well as colored light, in attracting attention to displays.

With the latest designs and arrangements of reflecting equipment, counts were made of the number of people stopping before the windows when lighted at various levels—from 15 foot-candles to 100 foot-candles. Similar counts were made with the light colored by means of screens over the openings of the reflectors. These figures were reduced to percentages, Fig. 77, of the number of people passing and showed remarkable increases in drawing power for the high intensity and colored lighting.

The investigators were convinced that, especially in the use of color, good taste is an important factor, and that the indiscriminate use of color is liable to defeat its own purpose.

Another investigation of show window lighting indicated that strong illumination provides the best known way of overcoming the interference of external reflection in window glass. This effect is most marked in the daytime, Fig. 78, and its correction, Fig. 79, demands stronger lighting than is ordinarily required after dark. It is proposed to utilize powerful spotlights to accomplish this result.

Fig. 76. Semi-indirect Portable Standard Providing Local Light and also throwing considerable light to the ceiling for general illumination

Probably no other class of lighting has witnessed a greater advance in recent years than that of school rooms. One illuminating engineering organization reported having handled more school lighting installations during the year than of any other corresponding application. The pupils certainly need as good illumination as the office workers, and their requirements have been woefully neglected in the past. Three foot candles was apparently generally regarded as sufficient in installations made even as recently as two or three years ago, and it was not uncommon to find standard classrooms equipped with only one outlet capable of carrying not over a 100-watt lamp. Much of the practice in the past year provided 8 foot candles or more. While considerable progress has been made, the vast majority of school rooms still seriously need more artificial light with modern diffusing equipment.

The engineers of the lamp manufacturers continued their investigations of the lighting requirements and conditions in various industries, issuing the results of these in bulletin form. Among others completed during the year were the wood-working industry, the textile industry, the food industries and the paper and pulp industry.

The action of artificial light on plant growth is still being given considerable attention. New investigators started experiments in this field and it is anticipated that in the near future elaborate equipment for experimental purposes will be available. A systematic and thorough study, with the various elements which enter into consideration of the problem carefully controlled, is planned. These tests should add appreciably to our knowledge of the subject.

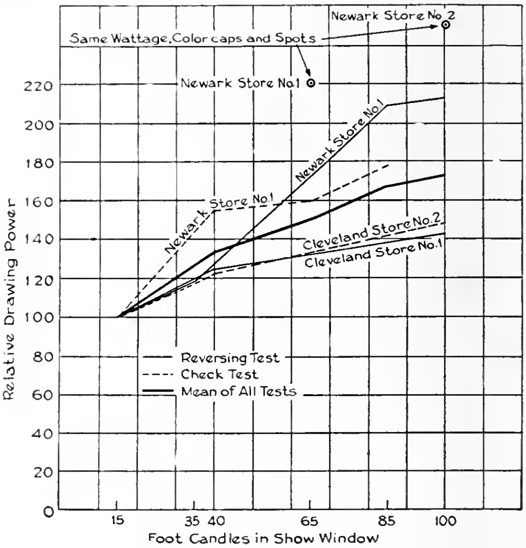

Fig. 77. Result from 106 Tests made in two different cities on show windows in four stores

Several temporary installations of mobile indirect lighting, made for certain special occasions, seem to suggest possibilities of enriching the artificial lighting of fine interiors and introducing some of the evanescence peculiar to daylight. In one instance, Fig. 80, by means of a motor rheostat device, colored lamps in indirect lighting pedestals projected bands of blending colors on the ceiling. These bands or waves of color moved across the ceiling so slowly that the motion was practically imperceptible. The colors were so balanced that color was not dominant in the lighting of the tables. Shaded lamps of various colors were strewn along the tables and enriched the illumination with spots of color. The effect was recognized as remarkably attractive and interesting by those who dined under the illumination.

Daylight has generally been regarded as a free gift. Under modern conditions, however, with large high buildings crowded together, the cost of providing light wells, and of supplying the heat lost through windows, is oftentimes greater than that of artificial light. During the year a paper was presented, which, without going to the other

Fig. 78. View of figure in window by natural light with the camera so located as to show the reflections of the sky line of the street opposite the store. It will be noted that the upper part of the figure is practically invisible

Fig. 79. Photograph taken under conditions identical with those of Fig. 78 except that special lighting had been turned on

Fig. 80. Lighting pedestals which project slowly moving bands of blended color on the ceiling by means of a motor rheostat device

extreme, points out that these factors should be rationally considered in connection with the financial side of the lighting problem.

Fig. 81. Model Living Room, Dining Room and Hall used in teaching good lighting practice

Fig. 82. Bracket-type Street Lighting Units at East Cleveland, Ohio

In order to facilitate the study and demonstration of lighting effects in the home, an exquisite model of two floors of an apartment house was built, with all furniture and lighting equipment exactly to the scale of one inch to the foot. The two stories of the model are furnished and finished the same—one apartment having excellent lighting and the other illustrating many of the common faults in ordinary home lighting installations. The model presents a very unusual opportunity of comparing and contrasting lighting effects, room by room.

During 1921, street lighting was the only phase of electrical activity in which progression was unimpeded. During 1922, still further advances were made and more street lighting material was purchased and installed than in any previous year. There was a greater appreciation on the part of the general public of the value of brighter streets, and financial conditions made it possible for public utility corporations to at least partially meet the demand thereby created. Many improvements were made in devices and in operating methods.

The application of ornamental lighting was chiefly limited to "White Ways" but during the year there was a definite trend toward a wider use of this class of lighting, not only in business districts but also in residential streets, boulevards and parks. The conditions to be met with respect to foliage and distribution of light stimulated the development of units which were not only ornamental but highly efficient.

A bracket type of unit was adopted for relighting East Cleveland, Ohio. The pole lines were all carried in alleys, and the feeder lines were brought out underground to slender, graceful standards in which the Mazda lamp is surrounded first by a Holophane dome refractor to divert the rays to the street surface, Fig. 82, and then inclosed in an alabaster rippled globe.

Fig. 83. Ornamental Lantern Type Lighting Unit

Fig. 84. Great Northern Ore Docks, Superior, Wis., illuminated by Highway Lighting Units

The location of a large number of ornamental units spread over a wide area gives added importance to features which reduce the cost of maintenance. Lantern type units, Fig. 83, with comparatively small flat panels of glass not easily broken in handling, and replaceable at low cost, were selected for a number of important installations; Cleveland and St. Paul being notable examples.

The elimination of globes as exemplified in a specially designed unit has demonstrated its value for certain types of residential lighting. Rochester, New York, continued to extend its illumination of this character and several other cities made similar installations. Maywood, Illinois, is being completely lighted by over 1700 of these units.

Improvements in luminous arc lamps included the use of rippled globes, more effective reflecting devices, and electrodes of longer life and higher efficiency. Compressed electrodes of square or oval shapes were found to give double the life previously secured and proportionately diminished trimming costs. For the highest class of illumination, the luminous arc lamp still finds extensive use. Important extensions to existing systems were made in Detroit, Salt Lake City, Buffalo, Toledo, Philadelphia, Pittsburgh, and other large cities.

There was an increasing realization by the general public of the dangerous conditions which exist at night, on unlighted highways handling high speed congested traffic. The Novalux highway lighting unit introduced in 1921 has made a splendid record of progress and installations have already been made in every section of the country, with the result that public sentiment is demanding the use of light as a preventative of present highway conditions.

About 48 per cent of the inhabitants of the United States live in the country and must use highways to reach shopping and market centers and an increasing percentage of the urban dwellers are also now using these highways at night, Fig. 85, both for pleasure and commerce. Congestion at many points is such at the present time that the installation of highway lighting units is justifiable from an economical standpoint alone.

It is almost unbelievable that with all the interest in the lighting of streets such important by-ways as alleys have been almost entirely neglected. Crime prevention is not complete when brightly lighted streets are paralleled by dark alleys. The distribution of light from the highway lighting unit suggests an ideal solution for this problem. The narrow alley-way may be brilliantly illuminated for a total length of 600 or 800 feet by the installation of these units with 250-candle-power Mazda lamps. A number of cities are now giving this problem careful consideration.

Other important uses were found for the highway lighting unit and during the year they were applied in the illumination of ore docks, Fig. 84, bridges, railway crossings, industrial railways, factory streets and for the general lighting of long narrow areas.

Fig. 85. Highway Lighting Illumination, Miami, Fla.

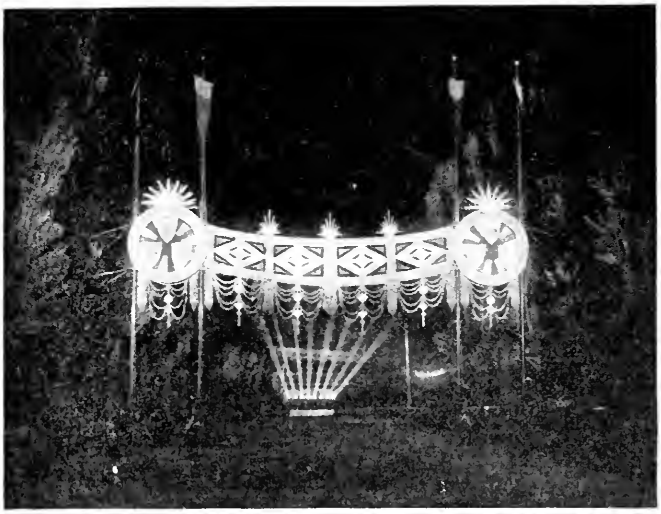

Fig. 86 Arch of Jewels Illuminated at Salt Lake City

A complete line of small tubes with tungsten contacts immersed in mercury was developed for low voltage switching operations. These units find numerous applications in electrical systems for making and breaking contacts. They can be utilized not only in connection with traffic signals and street lighting units, but also in the control of electrical units operating in the industrial field.

An improvement in the projection of motion pictures using the Mazda lamp as a light source was made possible by the introduction of a split condenser. Sufficient glass was taken from the center of the condenser to make the two halves slightly offset the projection of the filament images, thereby interposing on the curtain the bright bands of one field on the dark bands of the other. The resultant field is evenly illuminated and the intensity increased by 50 per cent due to greater permissible concentration of light on the film.

Following the success of the magazine type of film for use in the series socket for street lighting, the same idea of using a roll of ribbon fuse was incorporated in a renewable plug fuse for interior wiring.

The outstanding lighting demonstration of the year was the illumination of the Brazilian Centennial Exposition at Rio de Janeiro. In general, a lighting scheme similar to that used at the Panama-Pacific Exposition was selected except that in many instances the lighting sources were not concealed; brilliancy being subdued, however, by decorative fixtures and the use of color. Prominent features were the dome of the Palace of States,* decorated with 40,000 jewels, and the Avenue of Nations which was lighted by thirty standards, each carrying five 1000-candle-power incandescent lamps in lanterns. The general illumination of the building façades was by means of banner and cartouche standards, each with four 1000-watt lamps. Towers, domes and minarets were floodlighted by incandescent projectors and searchlights and the shadows thus created relieved by concealed red light.

It is noteworthy that the engineering, estimates and designs for this elaborate lighting project were completed in seven weeks and the entire contract including the manufacture of all electrical equipment, fixtures, etc., and their installation, was executed in six months.

Fig. 87. Panchromatic Fountain at the Pittsburgh Electric Show

Spectacular lighting played prominent roles at the Rocky Mountain Electrical Exposition at Salt Lake City and the Pittsburgh Electric Show. At the former an arch of jewels, Fig. 86, was lighted by arc searchlights and at the latter show the principal feature was an illuminated panchromatic fountain, Fig. 87, surmounted by a huge crystalier composed of 20,000 jewels.

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* A photograph of this illumination is shown as the Frontispiece of this issue of the Review.

Electric Drive for Turbine Auxiliaries

By John M. Drabelle

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The author gives the rating of the electrically-driven turbine auxiliaries in his power station, describes their automatic operating features, and gives operating data of the results obtained. He is a strong advocate for driving power house auxiliaries with electric motors in preference to any other method.—Editor.

The application of the electric drive to station auxiliaries of all kinds, due to the economies that are possible in the way of greater efficiency and lower costs of maintenance when compared with a small steam engine or turbine, is receiving more and more attention. The general tendency in power plant design is towards the auxiliary turbine for securing heat balance and to drive the various auxiliaries of the station with electric motors, with the exception however of the boiler feed pump. This article presupposes the condition that an auxiliary turbine has been installed for the purpose of maintaining a heat balance and supplying the auxiliaries with electric power.

An application of the all-electric drive for a steam turbine has been made by the Iowa Railway and Light Company at Cedar Rapids, Iowa, on their unit No. 5. This unit is a Curtis turbine—10,000 kw., 12,500 kv-a., 1800 r.p.m. The condenser is of the surface type supported on spring supports and has 18,000 sq. ft. of surface. The circulating pump is a Worthington pump with 24 in. discharge and 30 in. suction. This is driven by a 2200-volt G-E induction motor, of the wound rotor type for variable speed control. The vacuum pump is of Worthington manufacture of the Laidlaw feather valve type, size 29 in. by 18 in., driven by a 900-r.p.m. G-E variable speed induction motor. The hotwell pump of the same manufacture is a two-stage centrifugal with a four-inch discharge, working against an external head of approximately 45 ft. It is driven by a 220-volt, 725-r.p.m. G-E wound rotor induction motor.

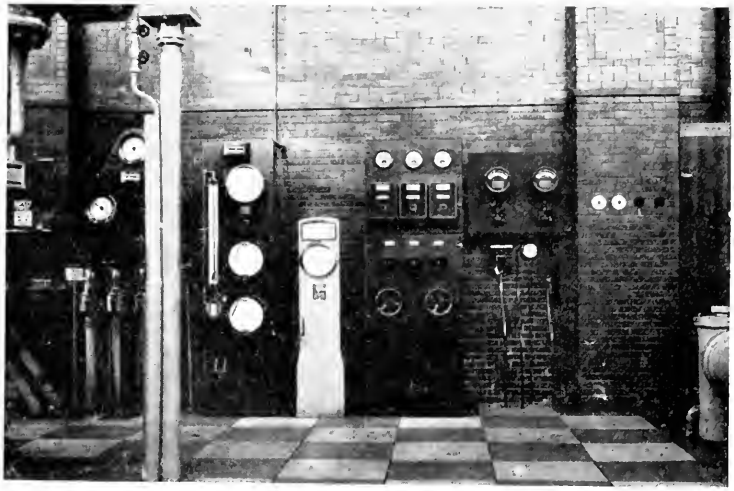

Fig. 1. Electric Drive of Turbine Auxiliaries permits of their centralized control by a panel such as that shown in the center of this illustration, which serves a 12,500-kv-a. turbine generator

The control of the hotwell, air, and circulating pump motors is handled by means of automatic controllers located in the basement near the auxiliaries to which they belong. The control of these contactor panels, however, is centralized on the control panel. The last named panel contains the watthour meter, ammeter and a push button station for each of the three auxiliaries, and in addition thereto an auxiliary drum controller for opening and closing the various contactors on the air and circulating pump panels. This permits the watch engineer to vary the speed of these auxiliaries from the main operating floor. With such an arrangement, the maximum flexibility can be secured, as well as greater ease in starting. Also from the watthour meters a record can be kept of the input into the several auxiliaries, thereby giving a continuous check on their performance from hour to hour. The voltage of the hotwell and air pump motors is 220 volts, supplied by a bank of transformers located beside the control board. The circulating pump motor is operated directly from the 2300-volt auxiliary bus and the control for this is an oil immersed contactor on the high voltage side, with standard contactors that short circuit the various banks of resistors on the low voltage side. Figs. 1 and 2 show the control panel with its push button stations, auxiliary drum controller, ammeters and watthour meters.

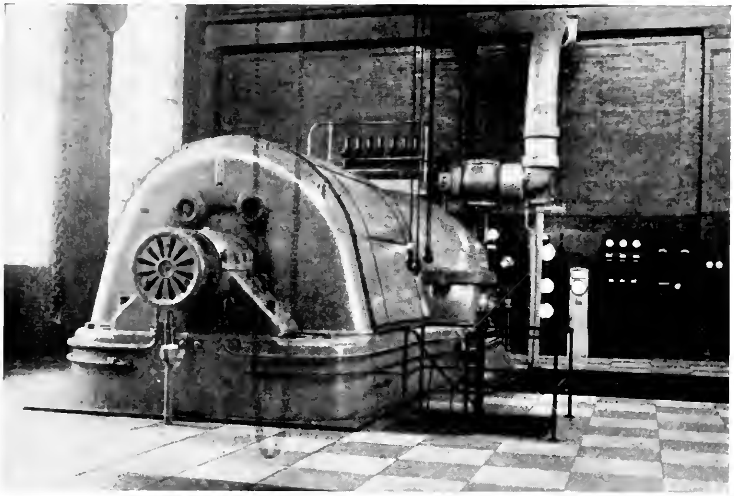

Fig. 2. Turbine Generating Unit No. 5 in the Cedar Rapids Power House of the Iowa Railway & Light Company served by electrically-driven auxiliaries controlled by a panel shown in the background, and close up in Fig. 1

This method of operating the auxiliaries with extreme flexibility and speed control is interesting. Except at very low loads, it is possible to operate entirely on the rise of temperature through the condenser. In other words, it is possible to maintain a constant temperature rise through the condenser at all times regardless of the load on the prime mover. As the load comes on, the watch engineer operates the controller increasing the speed of the circulating pump with a consequent increase in the amount of circulating water handled, thereby maintaining a constant temperature rise. The air pump is handled in the same way to maintain a constant absolute pressure. This pump is operated at the lowest possible speed without a drop in vacuum.

The time required for starting up the auxiliaries is reduced to an absolute minimum, it being only necessary for the operating engineer to push a button and that particular auxiliary will start up at once. The starting, being entirely controlled by an automatic current limiting relay on the contactor panel, insures the maximum of protection to the equipment at all times. The air, circulating, and hotwell pumps require but about one minute to start. Consequently, in case the prime mover is needed quickly there are no long delays in going to the basement and opening and closing various valves, as in the case with steam driven auxiliaries, or when handling hand-operated devices if electrically driven.

For the month of October, 1921, the operating statistics of Unit No. 5 are as given below.

Total generated	3,882,000 Kw-hr.
Vacuum pump	10,587
Hotwell pump	6,558
Circulating pump	46,169
Total auxiliaries	63,314

	Per Cent of Total Generated
Vacuum pump	0.27
Hotwell pump	0.17
Circulating pump	1.17
Total auxiliaries	1.63

Two typical daily operating curves are given in Figs. 3 and 4. These curves show the hourly generation of the unit and the total kilowatt-hour input into all of the auxiliaries, as well as the total separate input into the circulating, vacuum and hotwell pumps. Likewise, the percentage of auxiliary power to the total generated is shown. The absolute pressure in inches of mercury and the rise in the circulating water temperature through the condenser is plotted. In the month of November, shown in Fig. 4, the circulating water temperatures were much lower than in October, with consequent improvement in absolute pressure. A careful study and analysis of these statistics and curves will show:

(1) That the variable speed electric drive permits of greater flexibility and economies than a two-unit circulating pump drive, using either a constant speed electric motor or small steam turbines. That only sufficient water need be circulated at all times to take care of given load conditions and temperature of the circulating water. With the variable speed drive the maximum advantage is taken of the speed-torque characteristics of a centrifugal pump.

(2) That the variable speed drive on the air pump permits of greater flexibility to take care of the variation in the quantity of non-condensable gases carried over with the steam, and of permitting the operation of the air pump at the lowest possible speed at all times, for the wear on a reciprocating machine of any kind is reduced approximately as the square of the speed. These curves further show a very appreciable saving in power for the rotating dry vacuum pump when compared to the constant speed hydraulic vacuum pump whose power requirements are more or less constant and independent of the amount of air or noncondensable gases handled by the air pump.

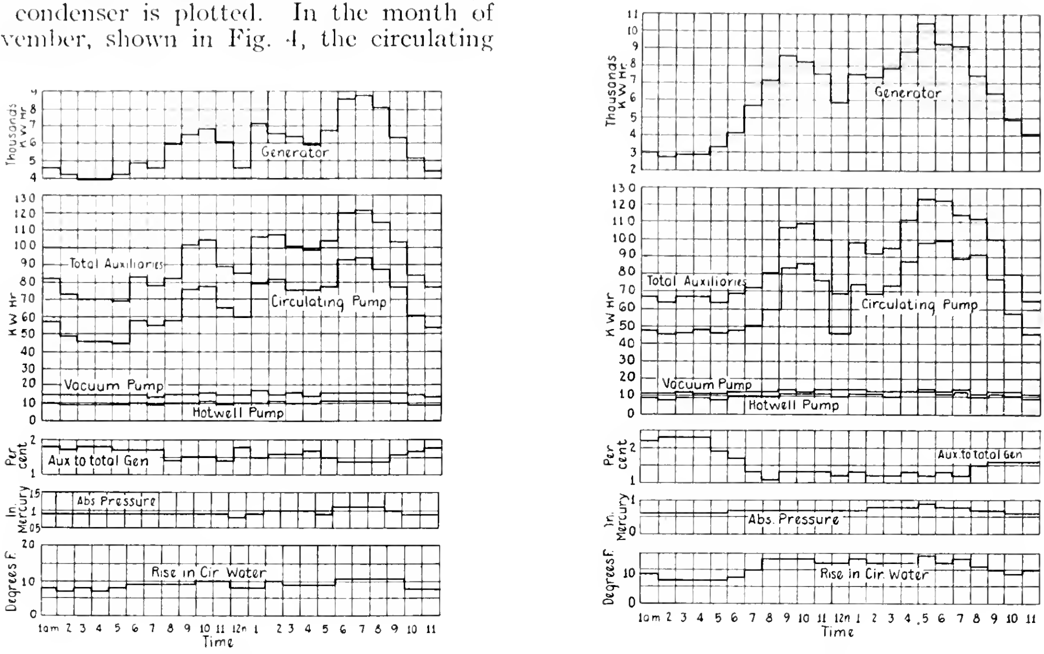

Fig. 3

Fig. 4

Figs. 3 and 4. Typical Daily Performance Curves of the Equipment shown in Fig. 2, for the month of October on the left, and the month of November on the right

(3) That it permits of extremely rapid starting of the station auxiliaries to take care of emergency conditions and requires but one man to start them.

This installation has been in continuous service since June 5, 1921, and has stood up successfully under every operating condition imposed on it without a single failure or case of trouble of any kind.

Modern Jet Condensers in Small Lighting Plants

By R. E. Hellmer

Engineer, Condenser Department, Schutte & Koerting Co.

Condensing equipment is essential to the economical operation of a steam power plant. For the purpose there are many makes of condensers but all can be grouped into two classifications; surface condensers and jet condensers. The question as to which is the better type to employ in a particular power plant should be determined wholly by the operating conditions that exist at the plant. In the following article the author describes a variety of installations of the type of condenser manufactured by the company with which he is connected.—Editor.

Condensers are generally classified into surface condensers, in which the exhaust steam and the condensing water are kept separated by the heat transmitting surfaces, and into jet condensers wherein the steam comes into direct contact with the water—the condensed steam, water, air, and other non-condensible gases are removed either by suitable pumps, a barometric column, or by means of the kinetic energy of water jets.

The choice of a condenser depends primarily upon the quantity and quality of water available for condensing purposes.

Where there is an abundant supply of fresh water that is sufficiently pure for boiler feeding purposes, the most suitable type of condenser to install is some form of jet condenser. Under these conditions such a condenser is probably the lowest in first cost and the most economical in operation.

The surface condenser is ordinarily chosen in instances where there is an abundant supply of cheap water, but of quality unsuitable for boiler feed. If the feed water must be drawn from the same source of supply, a water softening or purifying plant or an evaporator is necessary to make up the loss of feed water due to leakage.

If the water supply is limited, but of good quality for boiler feed, a jet condenser would probably be the best one to install, together with some form of recooling plant of sufficient capacity to reduce the condensing water temperature to a point low enough for continuous working. By limited supply is meant a supply that is not sufficient in quantity to be discharged to waste, and relatively expensive to obtain.

Where there is a limited supply of water, unsuitable for boiler feed, a surface condenser should preferably be installed and operated in combination with a water cooling plant of ample capacity for continuous working, and with a water softening or purifying apparatus to make up the loss in boiler feed.

The purpose of this article is to review briefly modern tendencies in jet condenser practice and to describe some typical small lighting plants and central stations where the low-level jet condenser is being used.

Fig. 1 shows the arrangement of a 1000-kw. jet condenser serving a General Electric turbine-generator unit installed in the Municipal Electric Light Plant, Lansdale, Pa. The condenser is designed to handle 22,000 lb. of steam per hour, and to produce a 27-in vacuum with 95 deg. F. water. It is located immediately below the turbine exhaust and is connected to the turbine by means of a copper expansion joint as shown. The diagram clearly illustrates the arrangement of the motor-driven injection and spray pumps. The condenser injection pump takes its suction from a cold well outside the power house. This cold well is supplied with water

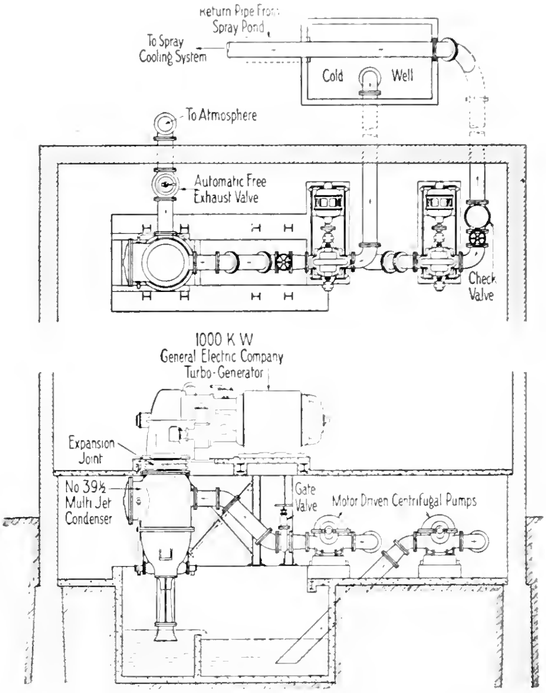

Fig. 1. Plan and Elevation of Jet Condenser Connected to a General Electric 1000-kw. Turbine-generator; Municipal Electric Light Plant, Lansdale, Pa.

from a spray pond located 300 ft. away. Provision is made to maintain the water in the hot well at the desired level by means of float controlled valves and switches.

The low-level jet condenser shown is of the ejector type; that is, the condensed steam, water, air, and other non-condensible gases are entrained and discharged by the water jets on the ejector principle. A sectional elevation of the condenser is shown in Fig. 2. The injection water is supplied under pressure to a closed cylindrical chamber (nozzle case) within the condenser and forced through a ring of converging nozzles, accurately designed to discharge a specified amount of water according to the conditions of flow as determined by the water pressure and the existing vacuum. As the water jets emerge from the nozzles, they are directed into the throat of the tail diffuser where they unite to form a single jet. The exhaust steam enters the condensing chamber through a top or side inlet opening, flows through the annular passages between the tapering rings of the combining tube, comes into direct contact with the converging water jets, and is condensed. Due to the combined effect of the external water pressure, the vacuum existing in the condenser, and gravity, the jets attain a velocity sufficiently high to entrain the condensed steam, air and other non-condensible gases, and to discharge them into the hot well against the pressure of the atmosphere. The water jets create the vacuum by condensing the steam, and maintain it by entraining and removing the air and other non-condensible gases.

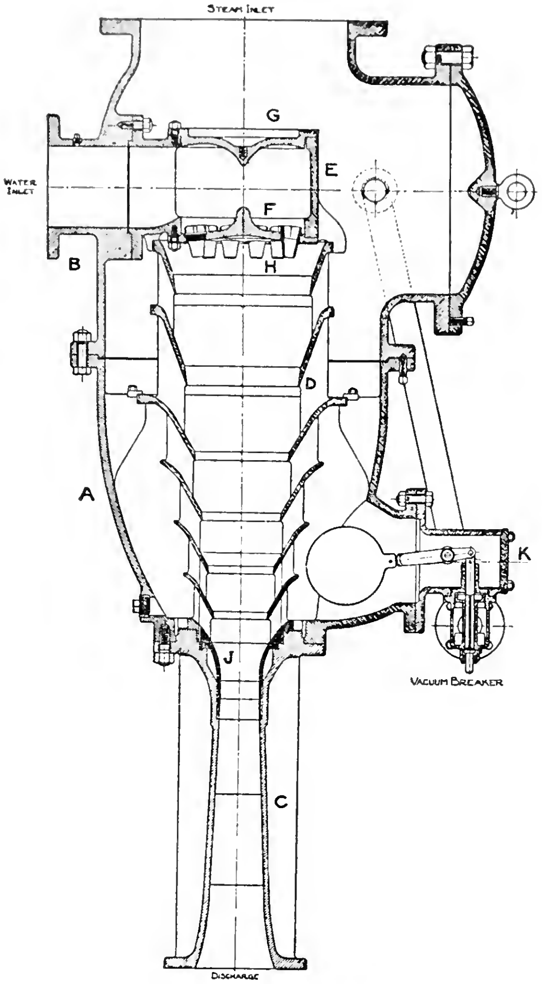

Fig. 2. Sectional Elevation of the Jet Condenser Shown in Fig. 1

The rings are so designed and arranged as to direct the steam flow parallel to the water flow. The discharge end of the tail pipe is submerged about six inches in the hot well, and is effectively water sealed against air entering the condenser body.

The condenser operates with a water pressure of 9 lb. per sq. in. at the condenser water inlet, equal to 21 ft. head. This pressure is sufficient to overcome friction in the tail pipe, and to discharge the water against the pressure of the atmosphere.

The motor-driven centrifugal injection water pump of the multi-jet condenser operates under conditions favorable to centrifugal pumps; that is, with a suction lift rarely exceeding 15 ft. Thus the maximum pump efficiency is obtained, which lies between 70 and 80 per cent.

Fig. 3 shows a typical twin-jet condenser installation that is finding favor with a large number of central stations. The installation shown is that at the Wellsboro Electric Co., Wellsboro, Pa. This plant operates a 300-kw. General Electric turbine-generator connected to two multi-jet condensers installed in parallel and provided with separate motor-driven centrifugal injection pumps. The dual arrangement makes it possible to shut down one condensing unit during periods of light load or during the cold season. It also provides a spare unit in case there is a necessity to overhaul or repair one of the condensers or pumps. Gate valves in the exhaust line permit either condenser to be cut out or started up without interfering with the operation of the other condenser. The flexibility thus provided has proven highly satisfactory.

The Bangor Electric Co., Bangor, Pa., operates a 750-kw. General Electric turbine-generator served by a multi-jet condenser arranged in the peculiar manner shown in Fig. 4.

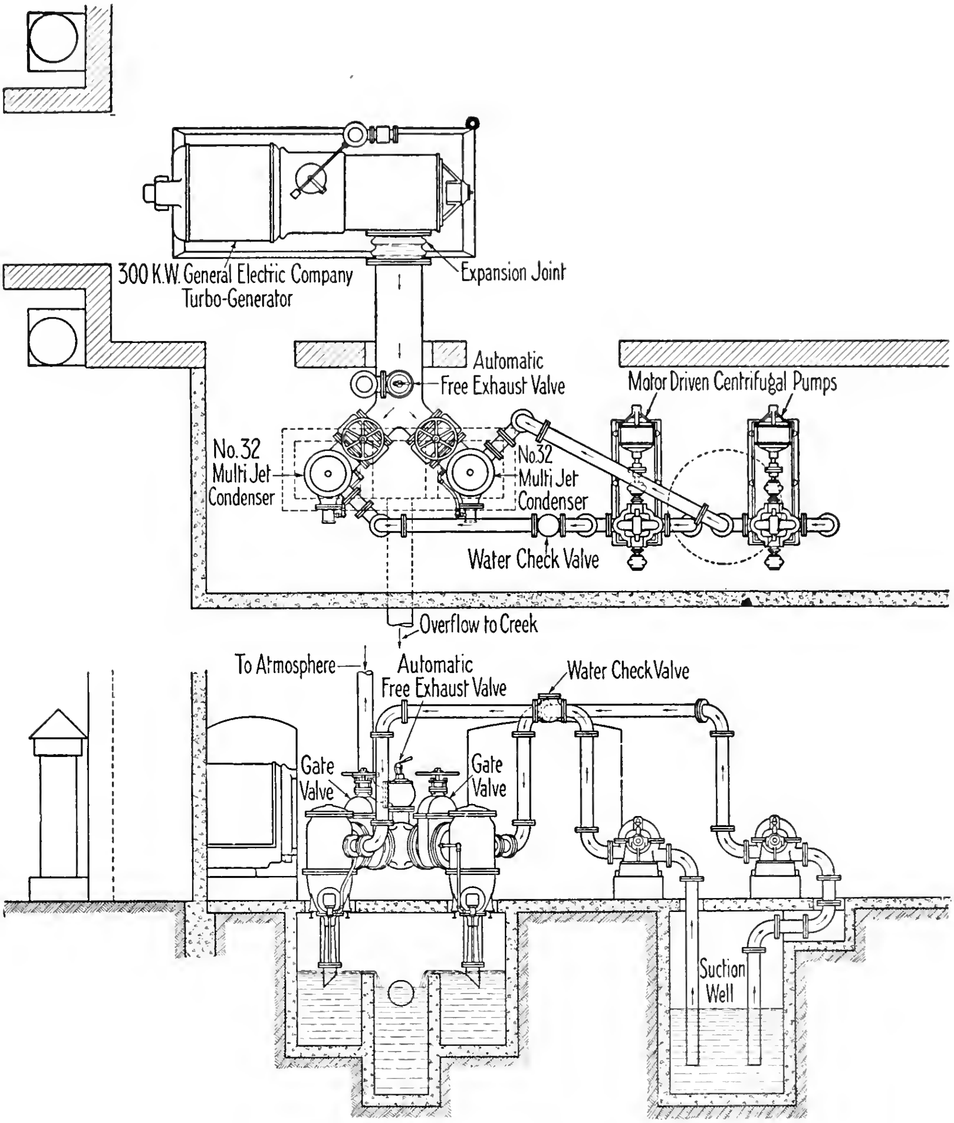

Fig. 3. Dual Arrangement of Jet Condensers Serving a General Electric 300-kw. Turbine-generator; Wellsboro Electric Co., Wellsboro, Pa.

The absence of a basement and the lack of sufficient head room to place the condenser in the customary vertical position made necessary its installation in a position inclined 45 deg. to the vertical. The pit containing the hot well was already in existence, and by building up the turbine foundation about four feet above the floor, the entire equipment was accommodated without the necessity of any excavation. The injection water for the condenser is supplied from an elevated flume, under a natural head of about 10 lb., and is discharged under gravity from the hot well to a creek alongside the power house. The water jets unite in the diffuser throat without perceptible deflection from the inclined condenser axis. The condensing unit operates

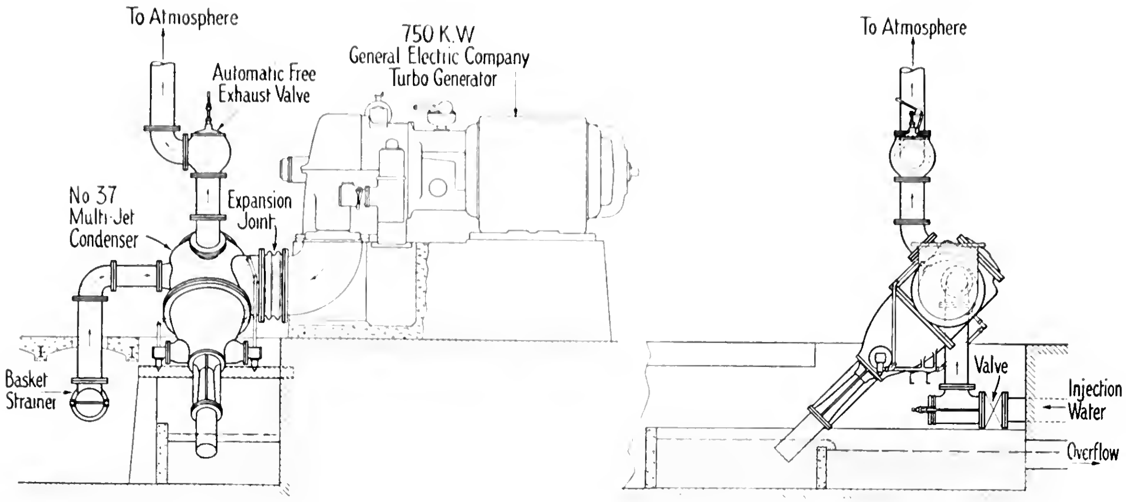

Fig. 4. Jet Condenser Inclined at 45 Deg. and Connected to a General Electric 750-kw. Turbine-generator; Bangor Electric Co., Bangor, Pa.

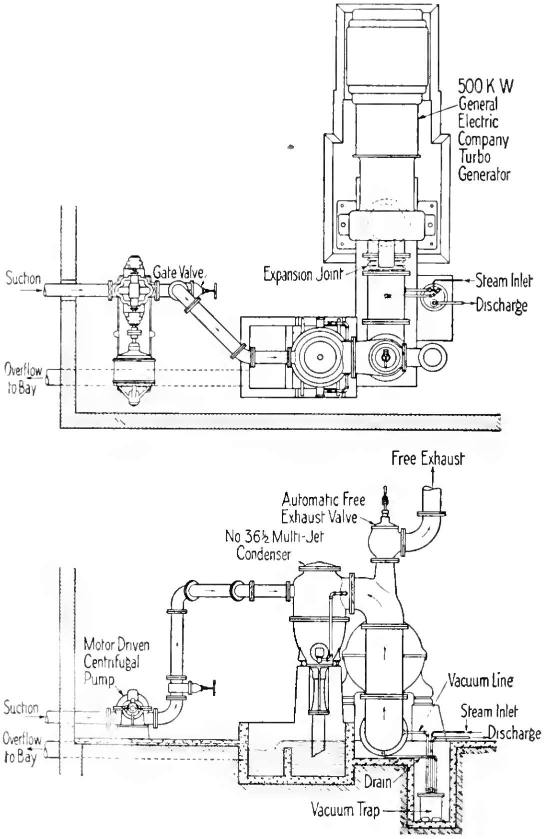

Fig. 5. Jet Condenser Mounted above the Floor Level and Connected to a General Electric 500-kw. Turbine-generator; Municipal Electric Light Plant, Edenton, N. C.

without any pumps whatever, and maintains a vacuum of 28 in. with 70 deg. water under full-load conditions.

The layout shown in Fig. 5 represents the condenser installation at the Municipal Electric Light Plant, Edenton, N. C., and shows a 500-kw. General Electric turbine-generator connected to a multi-jet condenser with motor-driven injection pump. The absence of a basement and the fact that the tide water from the adjoining bay rises to within two feet of the turbine room floor made it necessary to place the condenser above the floor line in order to provide for the gravity return of the hot-well overflow to the bay. The exhaust loop is drained by means of a vacuum trap installed about three feet below the lowest point of the exhaust pipe.

The Municipal Light Plant, Greenville, Texas, has recently installed a 500-kw. General Electric turbine-generator and multi-jet condenser designed to maintain a vacuum of 27 in. with 85 deg. injection water.

Figs. 6 and 7 show the condenser with motor-driven injection spray pumps. It will be noted that both pumps are connected to one motor. The usual procedure in starting up the turbine is to run the turbine non-condensing until full speed and the desired voltage are obtained. Thereupon the motor-driven pumps are put into service, and after the full injection pressure on the condenser is secured, the atmospheric relief valve is closed. This installation is typical and is successfully being adopted in a large number of small municipal lighting plants.

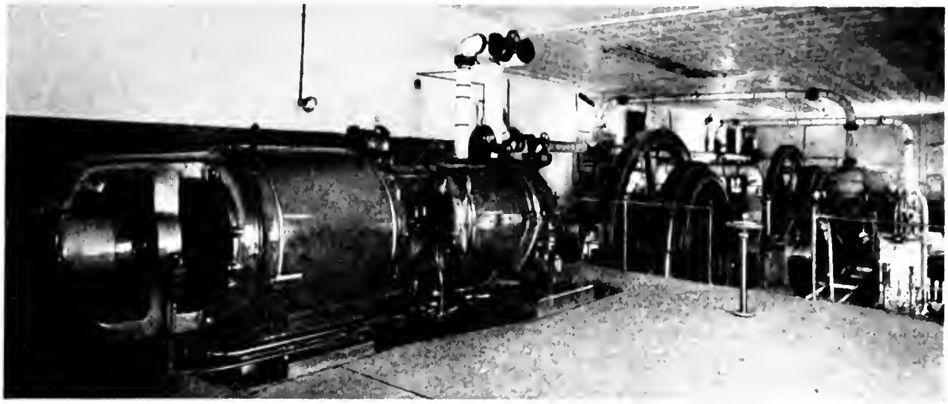

Fig. 6. 500-kw. General Electric Turbine-generator Installed at the Municipal Light Plant, Greenville, Texas

Table I is of interest inasmuch as it itemizes the data of a performance test conducted on a low-level multi-jet condenser of the larger size. This condenser is rated at 50,000 lb. steam per hr. at 28 in. vacuum and 70 deg. F. water. Although the test was conducted in summer, with injection water temperatures varying from 70 to 79 deg. F., the vacuum referred to a 30-in. barometer was maintained well above 28 in. The condenser served a 3000-kw. General Electric Curtis turbine, and the test was run under commercial conditions.

Fig. 8 gives the all-year performance of a twin multi-jet condenser operating under three-quarters load and under full-load conditions corresponding to 84,000 and 112,000 lb. of steam per hour respectively. This condenser is installed at the Westport Station of the Consolidated Gas, Electric Light & Power Co., of Baltimore, Md., and at no

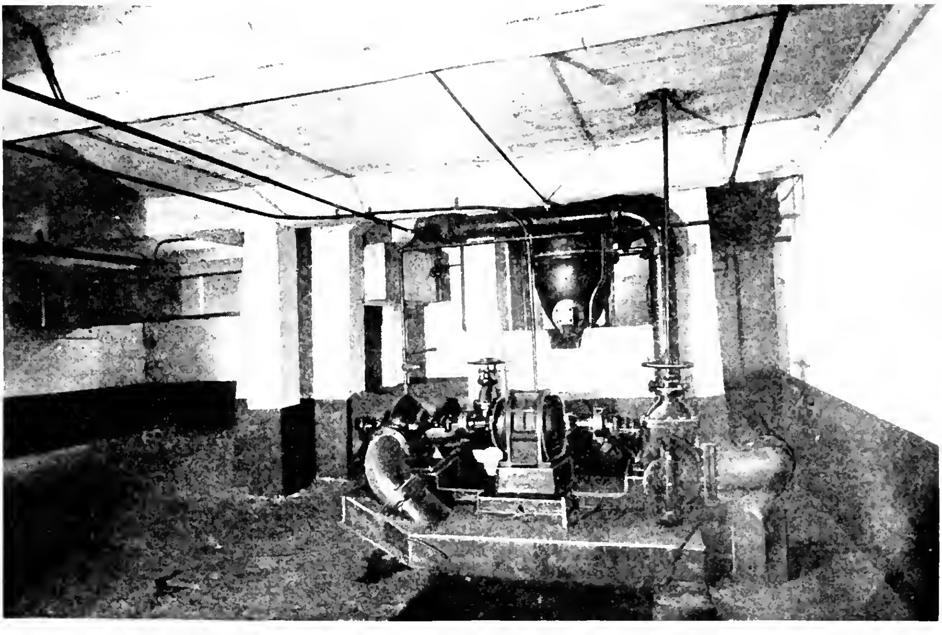

Fig. 7. Multi-jet Condenser at Greenville, Texas, Serving the General Electric Turbine-generator shown in Fig. 6. The condenser is shown in the background and is directly below the turbine

time does the vacuum fall below 28 in., not even in summer when the temperature of the injection water is as high as 78 deg. F.

The low first cost of the low-level multi-jet condenser readily permits the use of a separate condenser for each steam unit, which is an arrangement that insures flexibility and minimum operating cost wherever there are several steam units one or more of which are not in operation at all times.

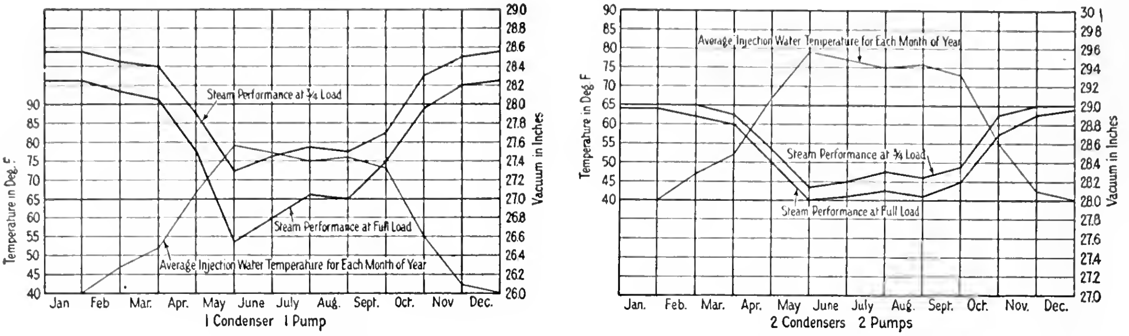

Fig. 8. Curves of Twin Multi-jet Condenser Performance at Three-quarters Load and at Full Load; Consolidated Gas, Electric Light & Power Co., Baltimore, Md.

TABLE I

PERFORMANCE TEST OF LOW-LEVEL MULTI-JET CONDENSER

Item		DATE OF TEST 1917										
		Aug. 20	Aug. 20	Aug. 20	Aug. 20	Aug. 20	Aug. 20	Aug. 21	Aug. 22	Aug. 23	Aug. 25	Aug. 25
Barometer, observed	in.	29.41	29.41	29.41	29.41	29.41	29.41	29.4	29.32	29.22	29.37	29.37
Vacuum, observed	in.	27.75	27.7	27.85	27.85	27.85	27.65	28.0	27.94	28.0	28.0	27.5
Absolute pressure	in.	1.66	1.71	1.56	1.56	1.56	1.76	1.4	1.38	1.22	1.37	1.87
Vacuum, referred to 30-in. barometer	in.	28.34	28.29	28.44	28.44	28.44	28.24	28.6	28.62	28.78	28.63	28.13
Injection water temperature	deg. F.	79	78	79	79	79	78	79	78	77	76	76
Hot well temperature	deg. F.	88	83	84	87	87	88	84	84	80	87	88
Vapor tension corresponding to hot well temperature	in.	1.334	1.137	1.174	1.292	1.292	1.334	1.174	1.174	1.032	1.292	1.334
Vacuum theoretical	in.	28.666	28.863	28.826	28.708	28.708	28.666	28.826	28.826	28.968	28.708	28.666
Air tension	in.	0.326	.573	.386	.268	2.68	.426	.226	.206	.188	.078	.536
Percentage of theoretical vacuum obtained		98.7	98.0	98.7	99.0	99.0	98.3	99.3	99.3	99.4	99.7	98.0
Water pressure, lb. per sq. in.		0	9	9.5	8.5	6	0	7	8	8.5	8	10.5
Water	g.p.m.	5520	7100	7150	7000	6600	5500	6780	7000	7600	7100	7300
Steam	lb. per hr.	28300	16850	17000	26800	25200	26250	16200	20000	10900	37350	41800
B.t.u. per one lb. steam		1045.4	1050.8	1049.4	1046.4	1046.4	1046.3	1046.9	1046.7	1049.0	1043.7	1047.2

Communication By High Frequency Waves

By John B. Taylor

Consulting Engineer, Lighting Department, General Electric Company

This title may give the impression that radio "broadcasting" and the use of "carrier" currents superposed on power lines are to be treated in detail. But a broad view of man's methods will disclose the fact that practically all forms of communication depend wholly, or in part, on the use of "waves." "High" and "low" are relative terms; most of the waves involved in all forms of communication are of "high" frequency in comparison with the "60 cycles" familiar to electrical engineers. The substance of this article was given as an address to the Southeastern Division of the N.E.L.A. at Atlanta, Ga., Sept. 15, 1922.—Editor.

"Communication" means the passing of a fact, thought or idea of one intelligent individual to another. Social intercourse and general carrying on of the business of the world demands the interchange of ideas or information between persons near each other or widely separated. Many and various devices have been utilized in the service, of crude form in prehistoric times, and becoming more highly developed with the progress of the race. The accumulated experience of the past and the latest inventions and scientific facts of the more immediate present are called on to aid communication.

Since an individual can receive impressions only through the senses (which are usually classified as five in number), we may consider first the relative importance of the several senses as they serve for receiving communication. In this service, the eye and the ear stand so far ahead of the other sense organs that touch, taste and smell may, for the normal individual, be almost dismissed from further consideration.

Facial expression and gesture communicate many ideas and serve as a basis for many actions, but, by far the larger part of communication is carried on by sound in the form of the spoken word, relying for its reception on the sense of hearing.

Now since sound is carried in the form of waves in matter, while light is propagated in the form of waves in space, it is apparent that these age-old means of communication have been dependent on waves. Audible musical sounds have frequencies which are limited to values between approximately 16 cycles and 16,000 cycles. While the fundamental frequency of the unusually deep voice of a man may be around 60 cycles, there are accompanying oscillations of higher frequencies than the fundamental. Recording methods indicate that the more important of these for the understanding of speech are in the neighborhood of 1000 cycles; so that, if we call 1000 cycles "high" on our reference scale of frequencies, communications by speech are by means of high frequency waves.

Those who are more interested in radio broadcasting than in power transmission may think of 1000 cycles as "low" frequency, but there should be no argument over whether the frequency for light waves (by which communications received by the eye are carried) is "high" or "low." The production of rainbow images from gratings composed of many ruled lines close together furnishes a method for computing the frequency of light waves of different colors, and if we set down the figure 5½, followed by 14 ciphers, we have what is approximately the average frequency of light. (550,000,000,000,000=550 trillion per second.) A somewhat lower frequency, say 400 trillion, gives a red light, while the extreme violet which is visible has a frequency of over 700 trillion—in round figures we may call it a quadrillion.

Our *lungs* and *vocal* apparatus may be regarded as power plants for generating and modulating variable frequency waves which are broadcast through the air.

Glow worms and *fireflies* possess apparatus for generating and transmitting the very high frequency waves of greenish light which may serve as signals or communications to others of their kind. However, the more communicative humans are not endowed with light-producing apparatus and visual communications are dependent on outside agencies such as the sun, moon, candles or electric lamps as generators of high-frequency energy. These may be started and stopped, or controlled and modulated by human thought and action. From this it appears that the great central station for supply of energy for visual communication is the sun, and, to continue the simile, we may say that whenever we communicate by look or sign using artificial light, we are drawing on energy from portable or isolated generating stations of energy in the form of high frequency waves.

Also, from time immemorial, men have used supplementary devices to extend the range of communication by means of sound waves. The drum, the trumpet, the alarm bell permit a man to convert a greater portion of his muscular energy into sound than do the lungs and vocal apparatus. Steam whistles and fog horns with motor driven air compressors are extensions of the drum and trumpet idea, drawing on and controlling power in excess of all that a single man or group of men together can supply.

The lower and upper figures for the sound frequencies ordinarily used are set by the receptive limits of the receiving ear and brain. With supplementary generating and receiving apparatus, it is possible to signal and communicate by sound waves using frequencies below, and also above, the audible range. There are certain advantages from a strategic standpoint in warfare and possibly other advantages under special circumstances in communicating by means of fairly high frequency waves, which give musical pitches too high to make any impression directly on the unaided ear. There are similar strategic and possibly commercial advantages in signaling and communicating, using light waves at frequencies outside of the comparatively restricted frequency sensibility of the eye. Thus, for example, infra-red rays or waves penetrate fog better than visible rays, and special projectors and receivers may be devised to communicate ship positions and avoid collisions at sea.

Similarly, the use of ultra-violet light for communicating permits the use of very simple receiving devices in the form of fluorescent material and has advantages in secret communications.

The working distance with ultra-violet light is limited because these extremely high frequency waves are readily absorbed. The infra-red rays, while less obstructed by the fine particles of mist forming fog, will, however, be limited in working distances, so that waves of still lower frequency are advantageous where great distances, with intervening objects and substantial curvature of the earth, are encountered.

Now, while entirely different methods and apparatus are employed for generating and controlling the waves of radio telegraphy and telephony than are used for producing and controlling light, many tests confirm the theory that the nature of X-rays, ultra-violet light, visible light, infra-red light, heat waves and electrical radiation differ only in numerical quantities and not at all in fundamental properties. The distinction between waves classified into these several groups, and sound waves (including those of too low pitch and too high pitch to be heard) is that sound waves are propagated in *matter* (either as gas, liquid or solid) while the "radiation" waves are propagated by space. And there is no known place or means of securing a cavity which will not carry electrical, heat, light or X-ray radiation.

A single candle throws its beam so that, under moderately clear air conditions, it can be seen for several miles. It requires a heavy bell or a powerful whistle or fog horn to be heard the same distance, even under highly favorable atmospheric conditions, and these favoring atmospheric conditions are seldom found. This comparison indicates one reason why communications over distances of several miles by lights or visual signals have been found more dependable and of greater range than sound signals. Though bell buoys and fog horns are used in large numbers, the navigator's principal reliance for many years has been on the lighthouse.

An earlier statement was that red light or infra-red radiation penetrated fog better than blue light, and, as the frequency of radiation is further reduced from trillions down to millions and tens of thousands, the limiting working distances set by absorption are advanced. Thus, the radiation art has been so extended that there is fair evidence that communicating waves completely encircle the globe.

From this line of presentation, we see that man has always been ready to make use of supplementary devices to aid him in his communications. Every new discovery or invention that serves toward this end has been pressed into service.

The writer was born within a few months of the time, and within a few miles of the place of Bell's successful experiments in communicating by speech over a wire. The "marvelous toy" proved to be something more than a plaything or a fad, and Alexander Graham Bell, who died this summer, lived long enough to see his invention so widely extended and generally used as to greatly modify the whole conduct of business and social communications.

In a parallel line, the experimental detection of electric radiation from a small spark has developed means for holding communication with ships in mid-ocean. There is even now no technical difficulty in so arranging that every individual in the country may at the same instant listen to a single voice.

There is another advantage in communicating by radiation waves in space rather than by sound waves in matter. The speed of propagation of sound waves in air is, roughly, a mile in five seconds, in water about four times as great, but in no known material is it more than 12 to 15 times as fast as in air. Imagine a solid rod of steel or wood in which sound is propagated with a velocity of, say, three miles in each second, and also imagine that this rod extends from Atlanta to Washington, a distance of 600 miles. If the absorption in the rod were so small that a sound wave started at one end could be detected at the other, the wave would require nearly 200 seconds (or about three minutes) to travel the distance. Six minutes would pass before hearing a reply to the first "Hello." Obviously, anything approaching a "conversation" over such a long distance telephone would be quite different from what we actually have with the electric telephone where the interval in a 600-mile circuit is such a small fraction of a second as to be altogether inappreciable.

A light wave or electric wave is one million times as fast as sound in air.

Before the practical development of wireless telegraphy and radio telephone broadcasting, experiments had been conducted using radiation from a beam of light as a speech carrier from a sending to a receiving station. An arc lamp at the sending end furnished the extremely high frequency radiation, a diaphragm vibrated by the voice increased and decreased the light, and a selenium cell at the receiving end served as detector and converter of the radiation. With fundamental features the same, a popular "360-meter broadcasting station" sends out waves of lower frequency than the radiation from the arc lamp. The strength of these 360-meter, or 833,000-cycle, waves goes up and down corresponding to the control exercised by each vibration of the spoken voice at the broadcasting station. Neither the eye, the ear nor any other human sense organ is adapted to take note of this radiation. The selenium cell which responded to the radiation from the arc lamp does not respond well at the broadcasting frequency of 833,000 cycles per second. Other devices like crystals or vacuum tubes are able to respond accurately to the high frequency currents. These detectors rectify the high frequency current and deliver to the telephone receiver a suitable form of current for producing sounds which reach the ear and are sensed by the listener.

Whether mankind will ever be endowed or acquire ability to receive electrical radiation as a sixth sense seems pure speculation.

It is common observation that light "travels in straight lines." This is equivalent to saying that intervening opaque objects cast sharply defined shadows.

We know, in dealing with sound waves, that there is a bending of the waves around objects of moderate size. It is a surprise to many to learn that quite small objects such, for example, as a ten-cent piece, may be held to cast a quite well defined sound shadow, provided the source of sound is of small dimensions and of high pitch. As a matter of fact, the sharpness of shadows and the bending of waves of any kind around opaque objects is determined by the relative dimensions of the object and the length of the wave.

"Wireless" waves are long in comparison with objects such as buildings, and it is difficult to find a spot effectively shielded from such radiation. This feature is an advantage in signals or conversations which are intended for broadcast reception, but a disadvantage where the communication is of a personal or private nature and a single line of transmission would be preferred. Such a single line of transmission, besides aiding the confidential nature of the communication, would permit the carrying on simultaneously of a large number of communications without interference; and, in the present state of the art, the interfering nature of one communication with another is more troublesome than the lack of secrecy.

Before the days of the electric telephone, speaking tubes connecting one room of a building with another or between buildings not too widely separated were frequently installed. These not only permitted the use of sound waves for confidential communication but the restriction of the waves by the walls of the tube conserved some of the energy so that greater distances could be covered in vocal communication through the tube than through the open air.

Parallel with the use of pipes and tubes for directing sound waves, we now see the ordinary telegraph, telephone, trolley wires and transmission line conductors used for the purpose of guiding and conserving a relatively small power in high frequency waves. These waves are superposed on the larger and more powerful currents for which the various electrical circuits have been initially installed.

Without going into detail on the particular pieces of apparatus and schemes of connection, we may say very generally that sending and receiving equipment is of the same form as used for radio telegraphy and telephony through space. In place of the "antenna" a condenser of moderate dimensions provides a path to lead the communication bearing "carrier" current onto the signal wire, trolley or transmission line.

The field is a fascinating one but limitations of time prevent elaborating interesting features. Possibly, in closing, a few words on a point which seems to bother the novice may be in order: The tuning of a radio receiving set so as to pick up, at will, one broadcasting station or another, and then to pick up amateur stations, government time signals, ships and transatlantic stations, appears to be a wonderful proceeding.

It is true that, in the midst of a confusion of sounds, we are able to concentrate the attention on one particular speaker or instrument, but the concentration appears to be mental more than a screening or filtering action in the ear itself. Among many visual signals, the eye is able to focus principally on one particular point or object, excluding entirely those which are outside the field of vision, and mentally excluding those which, while within the field of vision, are not the central object. If visual signals come from a given distant point, light of different colors may be used for simultaneous communications. An individual, by his mental capacity, may concentrate on a particular color, and this concentration is similar to the concentration on a particular voice or instrument. As an aid to receiving signals coming in different colors, colored glasses or filters may be used so that the individual sees only the color of that particular frequency which is transmitted by the filter before his eyes. This is really a process of selective tuning, and there is a close similarity between it and the tuning used with a radio receiving set.

There is a further similarity between the selective receiving of visual signals by setting the eyes in a particular direction and the use of aerial coils or "loops" for receiving radio communications. The "field of vision" of the coil aerial is broader than the field of vision in the case of the eye. Nevertheless, it is possible to set the coil so as to completely exclude an interfering station which may be working at practically the same wavelength, or frequency, as the station desired, provided they are in different directions from the receiving point.

At any given point in space, there is a condition resulting from a combination of many sources of radiation. The astronomer may direct his telescope, and, from the radiation at the object glass of his instrument, construct an image of any one of countless thousands of stars or other heavenly bodies. In like manner, but with different equipment, a radio receiving antenna or aerial coil may be set up. From the radiation striking the antenna or coil, a process of focussing and screening brings out the desired communication in code or in spoken words.

It is not likely that sending stations will ever rival in number the heavenly bodies, but the list is increasing and the limit is not in sight.

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE   Editor, JOHN R. HEWETT   Associate Editor, E. C. SANDERS

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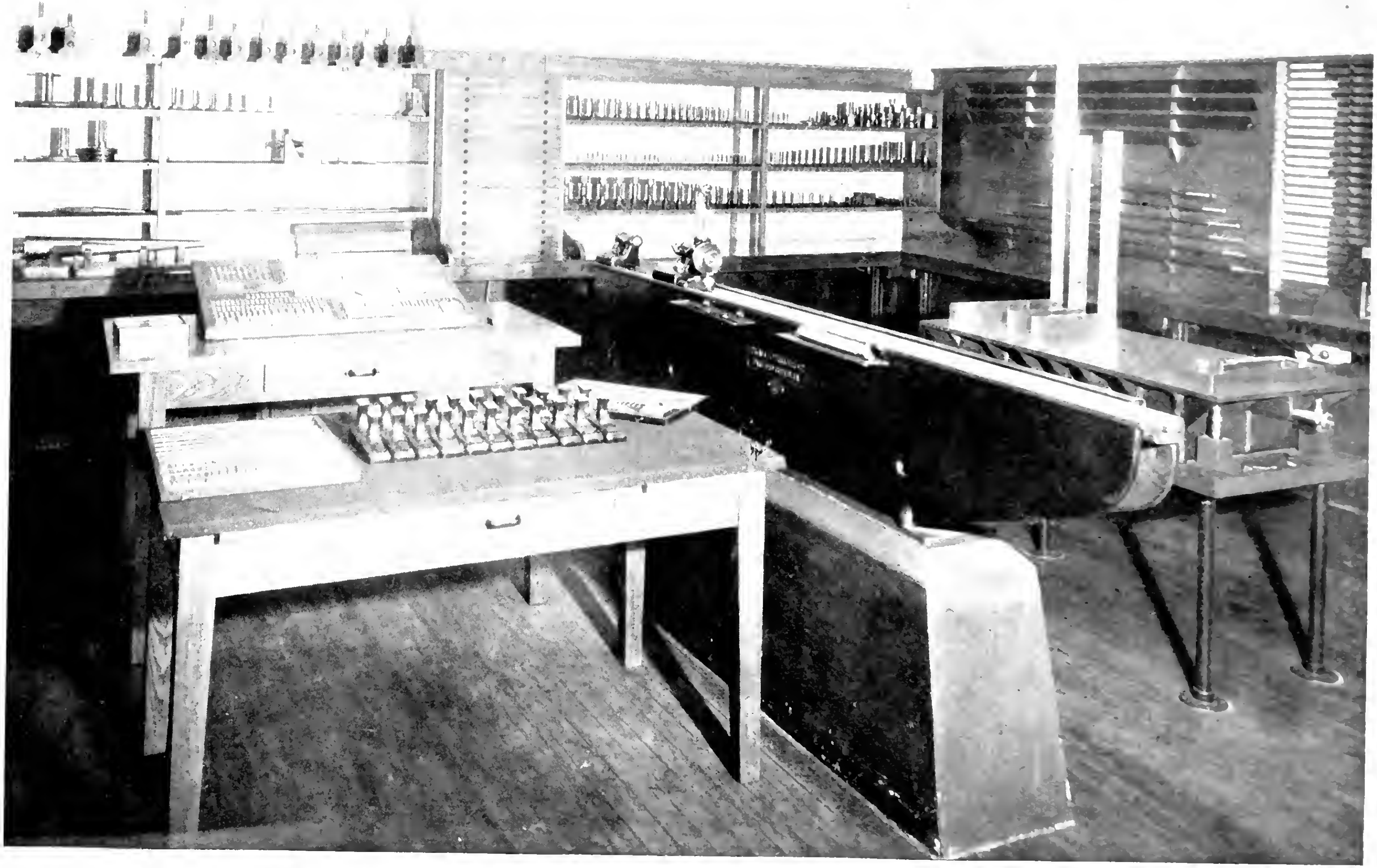


ONE OF THE GAUGE ROOMS AT THE SCHENECTADY WORKS OF THE GENERAL ELECTRIC COMPANY. (See page 110)

In modern manufacture absolute accuracy is essential. Parts made in different buildings or in different factories must fit absolutely and it must be possible to duplicate them at any time. The parts of a generator made in Schenectady must fit the parts of a waterwheel made in Switzerland when these are assembled in Africa!

GENERAL ELECTRIC REVIEW

WORK TO BE DONE

In a short article entitled "Notes on Wiring" published in this issue, the following most significant figures appear:

Estimated number homes in United States, approximately	21,000,000
Estimated number homes reached by electric lines, approximately	13,000,000
Estimated number homes wired for electric service	7,600,000
Estimated number homes reached by electric service, but not wired	5,400,000
Estimated number homes not reached by electric service, approximately	8,000,000
Estimated number homes connected during 1921	700,000

Each of these figures has a special lesson of its own;—21,000,000 homes in the United States.—America is a young country as nations go— and these figures show a national growth which is without parallel in history.

If the above figures indicate a marvelous national growth, what can be said of the fact that 13,000,000 of these 21,000,000 homes are reached by electric lines? Could any figures testify more eloquently to the fact that those great influences which have been at work, often with much opposition, to build up the industrial enterprises of the country have worked courageously and effectively?

Of the 13,000,000 homes reached by electric lines slightly over half, or 7,600,000, are wired. When we think of the age of the electric industry, the country may well be proud of this fact.

There are still 5,400,000 homes reached by electric service and not wired, and still 8,000,000 homes not within reach of such service. In one respect these last figures are the most interesting—they show a wonderful field for enterprise.

We have said enough to show that we appreciate the wonder of what has been done. But an appreciation of what has been done is of little value in comparison with an appreciation of what there is to do.

Now let us look at these same figures with a different mental attitude. Of the 21,000,000 homes in the United States only 7,600,000 are wired and 8,000,000 homes are not even in reach of electric service. Roughly speaking, there are two homes unwired for each home wired. Of the 7,600,000 homes that are wired, how many use any electrical appliances, excepting a few lamps? These are the things that are really worthy of attention.

How many homes in the United States are still doing family chores in the same silly old fashioned, back aching, nerve racking way as they were done a century ago?

True democracy depends upon giving all an equal opportunity—Those people who have no opportunity to use what man has done for man in the direction of taking the load off human backs and putting it on the machine have not a fair chance when compared with those who have this opportunity. Electric transmission lines may truly be called the nerves of a democratic state.

The electrical engineer has invented and developed hundreds of devices for reducing human labor. Why are they not used in every home?

It is a poor home where there is all labor and no leisure and recreation. We are told many alarming stories of the high per cent of our population that have the minds of thirteen year old children. We all know the effect of environment on evolution.

Are we wrong in building up the electric industry and believing in what it can do for our civilization?

We have only begun.

J. R. H.

Silica Glass or Fused Quartz

By Elihu Thomson

General Electric Company, Lynn, Mass.

Professor Elihu Thomson after giving a few historical notes tells how quartz is made and recites some of its many valuable qualities. The making of such large masses of quartz, when compared with what we could do a few years ago, seems but little short of marvelous. The research work which has led to these achievements has literally given the world new tools to work with.—Editor.

The element silicon is perhaps the most abundant of all in the surface layers of the earth and for many miles deep. It occurs only in the oxidized form. It has two oxides, SiO, or monoxide, and SiO_2, or dioxide; the former is not found in nature and became known as a laboratory product less than fifty years ago. It was often mistaken for the element itself, and in small specimens sold as such. Researches in the laboratory of the Thomson-Houston Co. in Lynn thirty years ago gave it its true place as monoxide, a dark brown inert powder.

It is, however, with the common oxide SiO_2 that we have to deal. This compound is the basis of innumerable minerals, simple and compound silicates which make up a vast variety of the rocks. Industrially they give us the clays, the micas, feldspars, which with the silica itself are so important in ceramics, coarse and fine, and in glass.

Fortunately, silica is found almost chemically pure in rock crystal, and in white veins in rocks, and is abundant even in white sands in an almost pure state. The sands used in making the finer grades of colorless glass are an example. For optical glass the highest grades are used; for plate and window glass a small percentage of iron can be tolerated, and this imparts the green color on edge view. Sand itself is not fusible by any temperatures which were attainable in ordinary combustion furnaces, but in the presence of basic metallic oxides, as soda, potash, lime, alumina, etc., fusion is readily secured, the product being some variety of glass, possibly. Mixed with clays, hardening takes place on baking at above a red heat, with bricks, tiles, and coarse pottery as a result, the hardening being due to the loss of water from the clay. When feldspar is added to the mixture of silica and clay, there is then, on prolonged firing in a kiln, a fusion more or less complete throughout the mass, and the result is porcelain of a grade depending on the proportions, the purity of the constituents, the fineness of the powders mixed, and the perfection of mixing and uniformity of drying and burning. These operations may be summed up in the phrase "perfection of working or manipulation." There is generally a subsequent firing for glazing or coating the ware with a more fusible covering which leaves the surface smooth and vitreous like glass, and which ensures non-porosity. It is the cracking or checking of this thin glaze layer which after a time spoils the ware, or, as in certain instances, which secures a surface deemed to denote a highly artistic result. This cracking of the glaze layer probably indicates a condition of strain due to unequal contraction of ware body and glaze on cooling which at last leads to fracture of the latter.

One of the results of feeding a blowpipe with oxygen instead of air was the discovery of the fact that the greatly increased flame temperature rendered it possible to fuse many substances which before had resisted the highest furnace temperatures. Among them was silica, or quartz itself, and more than a half century ago bits of rock crystal so heated were drawn into threads and later used for instrument suspensions, and were found to be almost perfectly elastic; far beyond other known materials in that respect. The instrument indices returned to zero after having been deflected. The quartz fibre untwisted itself completely after twisting through a large angle. It was many years after this that, working with the oxy-hydrogen flame, attempts were made to build up out of fused quartz, tubes or vessels for special uses, and about twenty years ago this had, as in the hands of Shenstone ("Nature," May 6, 1901), become a laboratory art practiced on a limited scale. The process was laborious and necessarily the product was very expensive. The writer foresaw more than twenty years ago that it was desirable to be able to work quartz on a much larger scale, that its properties were such as to give it a high value for a variety of uses. Briefly, its very low, or almost negligible, expansion is perhaps its most remarkable property. Besides this, its high transparency, not only to rays of the visible spectrum, but to low heat or ultra red rays, as well as to the ultra violet invisible rays, might give it a unique place in optical and kindred work. Coupled with its low expansion, prisms might be made of it whose refractive index was independent of ordinary changes of temperature, while astronomical and other mirrors or optical apparatus could be constructed and be practically free from distortion during changes of temperature; a difficulty which was always present in glass mirrors being thus removed.

Morever, it was foreseen that the optical working of true surfaces would be greatly facilitated because the work could proceed regardless of the slight heat generated in the polishing process. And again, for the same reason, the question of annealing to avoid strains became of far less importance, almost negligibly so, in fact. Another advantage over glass is that in the case of lenses or prisms, since the material is nearly 100 per cent pure, the formation of striae, due to inequality of composition, is minimized. Again, the low expansion allows the material to be ground or roughed into shape by an ordinary dry carborundum wheel, which, with glass, would cause fracture by heat, unless used with slow speed and great care. This last advantage applies in a general sense to the working of fused quartz into shape by grinding.

Fig. 1. Solid Ingot of Opaque Fused Quartz, Weight 115 Lb.

Besides the optical possibilities before alluded to, the value of fused quartz in the construction of chemical vessels, and conduits for conveying corrosive vapors, even at high temperatures, early became evident. And further, its properties made it desirable to investigate its possible application as an insulator in electrical work.

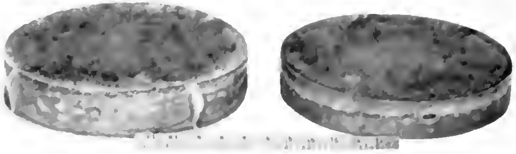


Fig. 2. (Left) Astronomical Reflector after grinding and polishing an 18-ft. radius curvature in the surface. (Right) Second Model Astronomical Reflector 11-in. dia. $2\frac{1}{2}$-in. thick having opaque quartz backing. Transparent quartz facing

About 1902, the writer began work to render it more easy to obtain fused quartz in masses as desired. An electric arc furnace was constructed at the West Lynn Works of the General Electric Company, and used to melt sand into slabs of several inches in diameter. One such slab was worked into the form of a concave telescope mirror and compared with a similar glass mirror for distortion of image under irregular heating. As was expected, the very great superiority of the

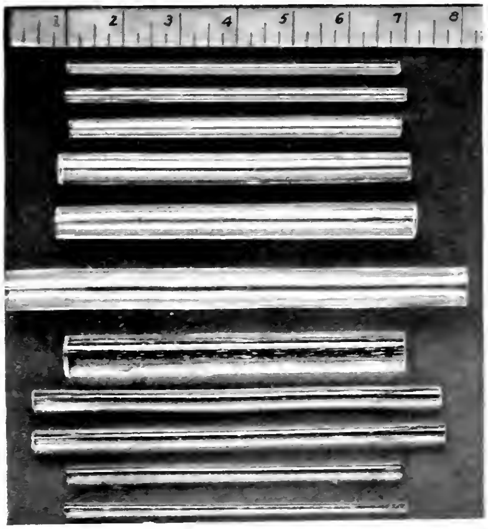


Fig. 3. Clear Fused Quartz Tubes and Rods made in Thomson Research Laboratory of the General Electric Company, River Works, Lynn

quartz surface over the glass was at once manifest. Changes of temperature which would absolutely destroy all definition with the glass mirror left the image formed by the quartz surface intact. But this was only a demonstration of what must have been the case as predicted from the relative expansion coefficients.

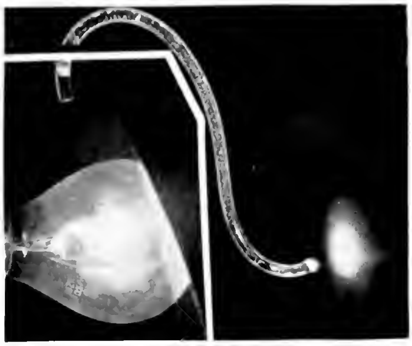


Fig. 4. Double Curved Fused Quartz Rod showing transmission of light through rod

At the same time, in 1902, in the Works at Lynn, there was another means of working fused silica developed, and this forms the subject of a U. S. patent, Number 778,286, to Elihu Thomson, "Manipulation of Refractory Material," December 27, 1904. The method itself as found out later, was foreshadowed by Despretz in 1849, who passed a voltaic battery current through a small carbon rod bedded in sand, and secured a small fused silica tube surrounding the same, but the Despretz experiment was unknown to the writer when he began work and lay buried in the literature of the early years as an isolated experiment.

Fig. 5. Two Clear Fused Quartz Slugs made in the Thomson Research Laboratory, General Electric Company, Lynn, Mass., April 27, 1922

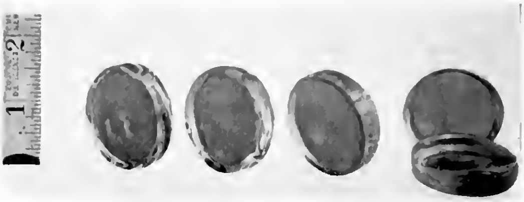


Fig. 6. Five Quartz Disks

The writer's plan was to bury in sand a carbon conductor shaped as a mould and to heat it electrically by current, thus causing the sand to fuse where it lay in contact with the mould. This action as continued gave rise to a thicker and thicker fused layer, and when the current was cut off, this layer formed the object required. It might be a tube of fused quartz or a dish, according to the shape of the carbon mould. The process was found to work well, and was, at the writer's suggestion, practiced by Dr. R. S. Hutton of Owen's College, Manchester, England, and an exhibit of articles so made was brought before the

Fig. 7. Samples Clear Fused Quartz Optical Grade made in Thomson Research Laboratory, General Electric Company, River Works, Lynn

Royal Society at the time. Dr. Hutton credited the writer with the origination of the process.

Fig. 8. Lenses (2) and Prisms (3) of Clear Fused Quartz

Lack of facilities and interference by other work and unfavorable conditions postponed any further development for several years, but the material was used at times for procuring at very low cost tubes of fused quartz as required for laboratory use.

Made from sand or quartz granules, the ware, so to speak, is translucent, not transparent, and this is owing to the innumerable small bubbles enclosed in the mass. For many purposes, they are not to be considered detrimental, and it is easy to imagine that cooking vessels may be produced of such ware, which will not break by sudden heating, or quick cooling even from a red heat, which can be thick enough to stand rough handling, and which can be cleaned, if need be, by burning them off.

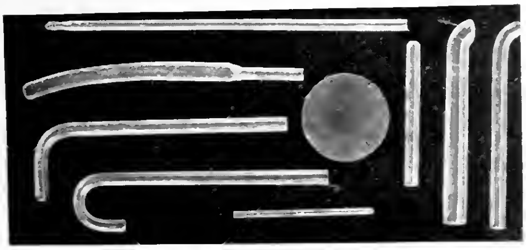


Fig. 9. Fused Quartz Applicators (8) and One Quartz Window made for Burdick Cabinet Company, Milton, Wis.

Be that as it may, many uses are being found for this coarser variety of fused quartz, and a consistent line of research has been carried on in producing it and shaping it by moulding, blowing, and grinding. It can readily be produced in masses weighing hundreds of pounds, and though containing innumerable small bubbles like half melted snow, these do not interfere with the properties of the quartz itself, as to low expansion, etc., see Fig. 1.

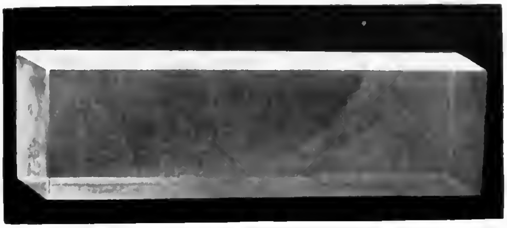


Fig. 10. Rectangular Bar of Clear Fused Quartz $4\times1\frac{3}{32}\times\frac{23}{64}$ in. made in Thomson Research Laboratory, General Electric Company, Lynn Works

It has been noted that the heating of a mass of quartz throughout occurs with rapidity in spite of its low heat conduction, and this fact may probably be the result of the great transparency to low heat rays or radiation, one part of the mass heating its neighbor by transmission of the radiation, so that a mass heated from the outside radiates to the interior in all directions, raising the temperature in spite of the low heat conduction of the material. On account of the low expansion, rapid heating of a mass is possible without fracturing.

Fig. 11. Model No. 1 Fused Quartz Insulator after being taken from the furnace

It is, of course, desirable that the sand or granular quartz used as a raw material be nearly pure silica. The fused mass is vitreous throughout and impermeable to gases or liquids, and has a surface in certain instances which has a glazed appearance, so that no glazing is called for. On account of the low expansion, also, metals, even steel, can be cast into openings after the material is formed.

Crystalline quartz on being heated expands unevenly in the line of the different axes of the crystal or along the main axis 781×10^{-8}

for each deg. C. per unit of length and in the transverse direction to the main axis about 1419×10^{-8}. In heating, if the access of heat is slow, crystobalite crystals form which are changed to tridymite as the temperature is increased.

Particles will begin to fuse together at 1400 deg. C. in the case of the purest rock crystal which, however, may contain about $^1/_5$ per cent of impurity acting as a flux. Further increase of temperature gives rise to partial fluidity or plastic condition, and at about 1750 deg. C. the silica in the open begins to sublime, but is still viscous like thick molasses. A higher temperature can be reached by fusion under pressure, which holds down the sublimation with little benefit however.

Fig. 12. Ingot of Opaque Fused Quartz weighing approximately 100 pounds. Six feet long and six inches in diameter

The change from the original crystalline form involves an expansion amounting to about 17 per cent of the volume, and on subsequent cooling to ordinary temperatures, the shrinkage will be about $^1/_{15}$ of one per cent only, a most exceptionable circumstance. Measures of expansion of fused quartz show that it expands at a slightly increasing rate as the temperature rises, but that on the whole the increase of dimensions is extraordinarily small, or such that with a change of temperature of 1000 deg. C. a meter long rod will expand or contract only about ½ a millimeter. As a rough expression of the low expansion, it is stated to have about $^1/_{17}$ that of platinum, the coefficient of expansion being at 200 deg. C., 518×10^{-9}.

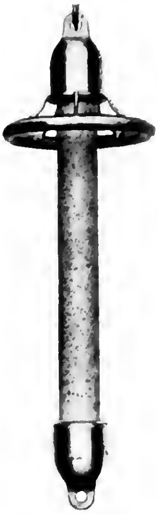


Fig. 13. First Model Fused Quartz Radio Insulator Complete with Corona Shield. Overall length 48 inches. Creepage distance 31 inches

At temperatures ranging from about 1100 to 1400 deg. C., and continued for a time, fused quartz undergoes gradual devitrification, a phenomenon which it shares with glass, some varieties of which are extremely susceptible to that action when under prolonged heating. Thoroughly devitrified quartz is white, granular and weak in structure and the property of low expansion which makes the fused product so valuable is entirely lost.

As before pointed out, the vitreous nature and acid resisting quality of fused quartz, even of the coarser or translucent material, coupled with the low expansion and consequent non-liability to fracture under sudden and great temperature changes, has led to the use on a considerable scale of fused quartz conduits and vessels in chemical industry. A single example will suffice. Formerly, the last stages of concentration of sulphuric acid from the state of dilution existing as manufactured in leaden chambers, to the strong acid known as oil of vitriol, was accomplished either by boiling off the water in glass stills, mounted over furnace fires, or in great platinum stills for the purpose. The glass vessels

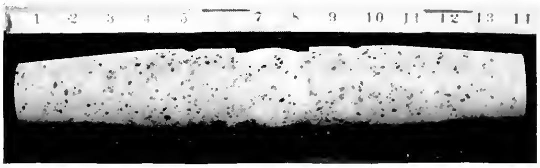


Fig. 14. Specimen of Cylindrical Grinding of Fused Quartz by a method developed in connection with the radio antenna insular problem

were slow in operation and very subject to breakage, they were large and expensive, and the spilling of acid into the hot furnace was little short of a disaster. The platinum stills, even at the relatively low cost of platinum many years ago, involved a large investment, one of them costing from $50,000 to $100,000. Their use was attended with gradual wear and loss of the precious metal. But its price today is many times what it was formerly. In this juncture the fused quartz evaporators worked in cascade accomplish the result without fear of fracture and at low cost of equipment.

By special methods developed in the laboratory of the General Electric Company at Lynn, it is now possible to produce many objects, not only of quartz of the opaque or opalescent character, such as is obtained by fusion of sand, but also to secure comparatively large masses of perfectly clear quartz as obtained from rock crystal, and containing only a few small bubbles widely separated; though progress along present lines will doubtless entirely eliminate them. There are also producible objects, such as disks for astronomical mirrors in which the body or backing is a thick mass of the sand fusion opal material, faced with a clear layer of the fine grade on which the optical surface is produced by grinding, polishing and figuring.

Considerable quantities of clear tubing are demanded for the construction of mercury arc lamps used for sterilization, and for other uses in which emission of ultra violet rays is the important factor. Such is the wonderful transparency of this clear material, that a rod or tube of it 26 feet long (the longest yet produced) will convey, by internal reflection, the light of a match from one end to the other with little apparent loss; and even bent rods convey in this same manner, light and heat rays through lengths of many feet.

Fig. 15. Fused Quartz Bushings used in high power rectifier development

Blocks of the clear material of optical quality are now produced, and there seems to be no especial limit to the size, excepting the scale of operation. Ingots, as they are called, are now made of varying size some of the larger of which contain from 50 to 150 cubic inches or more. These, when of high quality, furnish material for prisms and lenses of fused quartz, especially valuable in the construction of instruments dealing with the invisible rays, such as spectrographs for ultra violet rays. Besides, the constancy of dispersion of the fused quartz, owing to the small effect of temperature changes, is a valuable property in spectrographic work, generally. The refractive index for the D ray is about 1.46, while the relative dispersion $\frac{\mu - 1}{\Delta \mu}$ is akin to that of the lighter crown glasses.

Fig. 16. Fused Quartz Pedestals for supporting chemical tanks

The refraction is naturally much lower than that of crystal quartz, which itself being doubly refracting is given (for the D line) for the ordinary ray 1.54423, and for the extraordinary ray, 1.55338, decreasing with an increase of temperature.

Owing to the transparency to ultra violet rays, rods of clear fused quartz are now being employed to convey, from a vigorous source, such rays to the cavities of the body for treatment of diseased areas, such as in the throat, the nasal cavity, the ear, etc., where it would be impossible to place the source itself near the tissue to be treated. Internal reflection is relied upon to confine the bundle of rays which is emitted at the end of the rod; such rod may be bent or shaped to facilitate its use in such cases. Fig. 4 shows this effect with ordinary light rays.

In the same way, low heat rays (ultra red) may be conveyed and applied locally. An excellent example of this is seen on heating, by the oxy-hydrogen blowpipe, a rod of clear quartz of say 10 inches in length and about ½ inch diameter, holding it as usual with glass by the fingers some distance away from the heated spot, which may be the center section of the bar. Care must now be taken not to touch the flat ends of the bar, or a burn will result, though the temperature there is low. There is, however, an intense bundle of heat rays emitted at the ends, held within the bar by internal reflection from its sides.

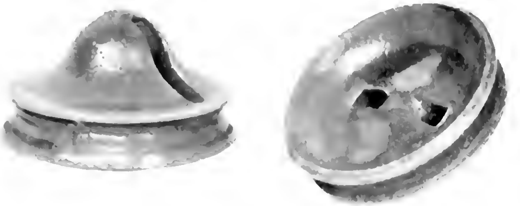


Fig. 17. Standard Petticoat Type 6-in. Strain Insulator made of fused quartz

The high grade clear fused quartz, in block, rod or tube form, is a very beautiful material, clear, colorless, and probably the most transparent solid in existence. It is the ideal glass. It can be welded when made plastic by heating, as with glass, but with no risk of cracking from sudden heating or cooling, a condition conducive to ease in blowing, drawing, bending or grinding it into various forms.

Tuning forks have been made from it which not only give a note decaying more slowly, but which can be adjusted in pitch without temperature change in adjusting standing in the way of accuracy, as in the case of steel; the variations unavoidably introduced having given rise to serious changes in standard pitch in the past few hundred years.

Thermometers and their tubes made of fused quartz have the merit of needing no correction for expansion, a serious matter in the case of glass where great accuracy is desired. They are not cracked by sudden temperature changes, and stand high temperatures without softening and deformation.

Disks of about a foot in diameter and about $2\frac{1}{2}$ in. thick of the coarser quartz faced with clear quartz are a recent triumph of the Lynn laboratory, and open the way to the possibility of relieving the astronomer of some of the trials and difficulties which he has had to endure in the use of glass, so subject to deformation by moderate temperature changes. Fig. 2 is a photograph of such disks.

Indeed, in the production of such disks, a new note has been struck, which may eventually lead to the substitution of fused quartz for glass in all important instruments of the reflecting type. The writer has had this problem in mind for two decades past, and it is a great gratification to him to have been able to solve it. Various means conducive to the best results are under way.

Coming now to the uses of the coarser (or sand melt) quartz in electrical work, it becomes at once almost obvious that for arc chutes it should be ideal as it is not excoriated or fractured by the sudden heat and is an excellent insulator even at high temperatures, vitreous throughout and non-hygroscopic. It can be moulded or formed by grinding into suitably shaped and fitted slabs and supports of metal may be cast into it.

Slabs can be cast with passages for resistance wires to heat them to desired temperatures for any purpose. Clear quartz may, in fact, be so prepared with a heater circuit as to be fitted for use as a window for clear vision in spite of deposits of snow, ice, water, or condensed vapors thereon.

Probably the major uses for the coarser quartz in the electrical industries in the near future will be in forming various types of insulators some of which are here illustrated.

Reference should properly be made in closing to the special article on "Quartz Glass" prepared by Dr. Arthur L. Day and E. S. Shepherd, of the Geophysical Laboratory of the Carnegie Institution, Washington, D. C., dated April 18, 1906, and published in *Science*, N. S., Vol. XXIII, No. 591, pages 670, 671, 672, which discusses the valuable work done in the preparation of fused quartz and the limitations found in the working thereof by the Geophysical Laboratory. The communication is worthy of a careful examination, and does much to clear up some of the doubtful points in regard to this interesting material.

Fig. 18. Standard 10-in. Hewlett Type Strain Insulator made of fused quartz

Studies in the Projection of Light

PART I

TYPES OF LIGHT SOURCES AND ANALYSIS OF PARABOLOIDAL REFLECTING SURFACE BY MERIDIAN AND SAGITTAL LINES

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

Artificial light as directly generated is of a "raw" character and must be "refined" before it can be most effectively utilized. This manipulation of radiated light is accomplished most readily when the source is the electric lamp, either incandescent or arc. How it is accomplished depends primarily on whether the purpose calls for a more or less diffused light or an intense concentrated beam. Most of us are familiar to some extent with the production of these two diametrically opposite effects; however, those who are interested in the gathering of light and its projection in the form of a beam will find information of great value in the following article and the others of the series which will appear in our succeeding issues. The present installment explains a most useful and unique scheme of optical analysis as applied to a reflecting paraboloid, commonly called a parabolic reflector.—Editor.

Introduction

In the art of illumination many wonderful things are being done. Everyone is familiar with the steady progress made in recent years in the lighting of our homes and streets; and a goodly number of us have seen spectacular wonders that were purely displays of light. Is there an automobile driver who has not given considerable thought to the subject of light, particularly when passing a glaring headlight and wondering just what he is going to hit in the darkness beyond? But it can be said in all seriousness that this particular problem of so projecting light that it will illuminate without glaring is one of the greatest engineering problems of the day, and perhaps by good fortune there may be something on the following pages that in the right hands will contribute to its solution.

It is in the particular field of projecting light to long distances that the art of illumination has reached its highest development. Here we find the largest lamps, the greatest consumption of electrical energy, the greatest collection of automatic devices, and the greatest example of manufacturing optics. In all the wide domain of illumination the lover of superlatives will feel most at home when speaking of the modern high-power searchlight. Here we deal not with illumination at ten feet or a hundred feet, but at thousands of feet, or, as the Army and Navy prefer to say, at thousands of yards. The mirror that *is* the searchlight may cost over a thousand dollars before it ever reflects a beam of light. But these figures become commonplace once the subject of candles is brought up. We calmly discuss a small searchlight that gives only ten million candles, and speak slightingly of a searchlight that gives fifty million candles, whereas another of the same size but of a later generation gives three hundred million candles. Then warming up to the subject we may relate what happened the night we operated a searchlight of seven hundred million candles. There have even been cases where, carried away by the exhilaration of the moment, we have talked of one billion candles until the dazed audience concluded that a *candle* must be about as valuable as a Russian ruble.

There are not many branches of art in which the accuracy of workmanship must increase with the size of the product, but this is exactly the case in the manufacture of a searchlight. While this article will not be confined to searchlights of notable size and power, or even to searchlights alone, yet as the ultimate aim of all endeavor is perfection so will the subject continually drift back to the largest because it is the best. The glass in the mirror of the automobile headlight may vary in thickness by several hundredths of an inch without great detriment, but the same variation in the thickness of a sixty-inch searchlight mirror would be fatal. The lamp in the flashlight may be a fraction of an inch removed from the focal point, and who cares? Let the crater of a high-intensity searchlight wander the same distance from the proper position and everyone cares. This same crater, while being held with precision at the focal point, is rotating about its axis and merrily radiating ten kilowatts of energy. And it must do this in foul weather or fair, on a heaving sea or when pursuing a frightened airplane with its mighty beam clear across the vault of the heavens. Truly, in the Domain of Illumination, the searchlight is King.

However, as with temporal kings, all searchlights are not perfect. In testing one of these proud monarchs it was discovered that several hundred million candles were missing. The test was repeated, with the same results. Three hundred millions gone. The King was sick, there was no doubt about that. The explanation was not found for many months and in the light of later events it would have been simpler to have doctored up the records than to have doctored up the King.

Much that is found on the following pages of this series of articles is the result of the hunt for the lost three hundred millions, but the bulk of the material is taken from papers presented before the Illuminating Engineering Society, from reports submitted to the Army and Navy at various times, and from other data taken from the files of the department and never before published.

TYPES OF LIGHT SOURCES

When designing a reflector for some specific effect in illumination, the first necessary information is about the light source; its size, shape, and brilliancy. If it is the intention to use a carbon arc the information is easily expressed by a formula or by a photometric curve with crater dimensions; a high-intensity arc is more difficult to define; and the incandescent lamp with its numerous helical coils in one or more planes is too complicated to be described by mathematics that are simple enough to be understood and used. To avoid these difficulties and reduce theory to practice with some degree of accuracy it is usual to substitute, in the design, some idealized form of light source for the actual source. Thus, the hemispherical or conical crater of the plain carbon arc becomes a disk, luminous on one side only, and the incandescent filament becomes either a disk luminous on both sides or a sphere uniformly luminous over its entire surface. The high-intensity arc on account of a certain dissymmetry in the distribution of brightness is the most difficult one of the three to match with a simpler substitute, but on the other hand the test data on this arc are fairly extensive and complete, and the need of a model is not so urgent. There remains one other type of source that is universal in its usefulness as a starting point of a design or study, but it is of very limited use when dealing with concrete cases because it exists only as a mathematical concept, that is, the "point source."

The nearest approach to an actual point source is furnished by the stars, which never show an appreciable diameter even when magnified by the most powerful telescope. The area of the star, not being measurable by this means at least, may be considered as zero, which agrees with our idea of a "point" as something that has location but no size. The light received from a star may be measured, and if we divide its total emission of light by its zero area we find that the surface must be infinitely bright. This reduces the matter to an obvious absurdity, and it illustrates some of the peculiar results that may be obtained in lens or mirror design unless the limitations of the useful but deceptive point source are kept constantly in mind.

ANALYSIS OF PARABOLOIDAL REFLECTING SURFACE

Point Source

A parabolic curve rotated about its axis generates a surface of revolution that has the useful property of reflecting light originating at its focus into a beam of light that is in general parallel with the axis. If the light source is a mere point then the beam is made up of a bundle of rays each strictly parallel to the axis, and there is neither convergence nor divergence of the light. The beam is thus cylindrical in form and of unvarying intensity at all distances, except as the light is scattered or absorbed by the medium through which it moves. The demonstration of these characteristics has been often made in books on photometry or geometry, and it would not be here repeated if there were not several useful principles of optics involved that are not so well known.

These principles, which will be explained shortly, enable us to analyze any section of a reflecting surface and find out in detail how it acts, what it can do, and what it cannot do. Also, they bring to light some interesting and useful properties of the paraboloid and related surfaces that seem to have escaped previous notice.

In the science of applied optics there is a phenomenon known as *coma*, by virtue of which the image of a point becomes not a point but two straight lines, perpendicular to one another in direction and lying in different planes. There is thus no single plane that will show an image that resembles the object, and it may be doubted if we are justified in calling either line an image of the generating point. Coma, in a camera, gives an image of a bright source some distance from the axis of the lens as a diffused point of light with a comet-like tail, and sharp definition is not possible in this part of the field. The rules that govern coma, in the simpler cases at least, are in themselves very simple, and because of this simplicity they are convenient (and powerful) instruments for the exploration of optical surfaces.

It may fairly be assumed that readers interested in the projection of light are familiar with the general properties of the conic sections, but if they feel any curiosity regarding the derivation of some of the statements here given as conceded facts, they can readily look them up in text books. This assumption will enable us to concentrate more on the principles of the subject in hand and avoid getting lost in a maze of incidental demonstrations.

Meridian Line

Let us take not a parabolic surface but the parabolic curve itself and see how it acts as a reflector. It may be necessary, in order to form a mental picture, to imagine that the curve has some little width and a flat surface on the concave side so that there will be something to reflect light. From the focal point of the curve draw a straight line at random to some point P on the surface as in Fig. 1,* and call the length of this line p, then if a is the angle measured clockwise from the axis up to the line p we have the following equations:

Equation of parabola (in polar coordinates)

$$p = F\ sec^2 \frac{a}{2} \qquad (1)$$

Radius of curvature at point P

$$R = 2F \sec^3 \frac{a}{2} \qquad (2)$$

where F is the focal length of the parabola as ordinarily considered in geometry.

Let us draw two rays of light parallel to the normal at P, Fig. 1, and find what they do after reflection at the two points P_1 and P_2 on the curve near P. According to a rule of elementary optics the two reflected rays will converge at a point on the normal, half the radius R from the point P. This point may properly be said to be the principal focus of the section of curve P_1, P, P_2, and designating this principal focal length by f_0 we get

$$f_0 = \frac{R}{2}$$

$$= F \sec^3 \frac{a}{2} \qquad (3)$$

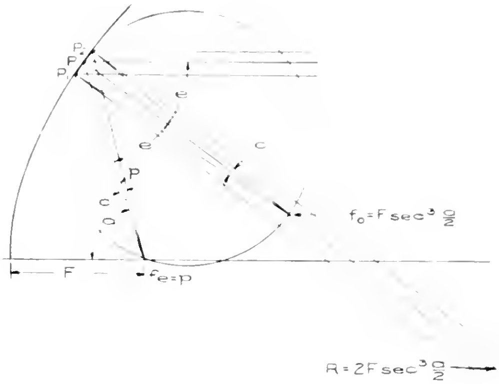


Fig. 1. Focal Properties of a Meridian Line

It will be observed that f_0 is measured along the normal, and hence does not coincide with what we ordinarily call the focus of the parabolic curve. Also, as the angle a is changed f_0 will change, so that each section of curve will have a principal axis, or normal, varying in direction and a principal focal length that varies in magnitude.

Consider the points P_1 and P_2 to be fixed, and rotate the incident rays counter-clockwise in the plane of the curve to some new position at an angle e, keeping the two rays always parallel to one another. The reflected rays will rotate in the opposite direction through the same angle e and the angle of convergence c will remain constant. The distance between the parallel incident rays will decrease by the factor cos e as they are rotated through the angle e, and if the rotation is made equal to 90 deg. the two will coincide in position. When the points P_1 and P_2 are fixed then the angle of convergence c of the reflected rays is fixed and independent of the angle of incidence.

We have for normal incidence the length

$$P_1\,P_2 = 2f_0 \tan \frac{c}{2} \qquad (4)$$

and at any angle of incidence e, we have the length

$$P_1\,P_2 \cos e = 2f_e \tan \frac{c}{2} \qquad (5)$$

---

* In this illustration, as well as in Figs. 2, 3, 4, 6a, and 6b, the symbols f_0, f_0', f_e, f_e', R, R', F, F', and F'' are used to designate both locations and lengths. Whether a location or a length is being referred to is explained in each instance in the text.

where f_e is the focal length or distance to the new converging point. Upon comparing equations (4) and (5) we get the relation

$$f_e = f_0 \cos e \qquad (6)$$

which shows that as e is varied the point of convergence moves in a circle that has a diameter f_0 and is tangent to the surface at the point of reflection.

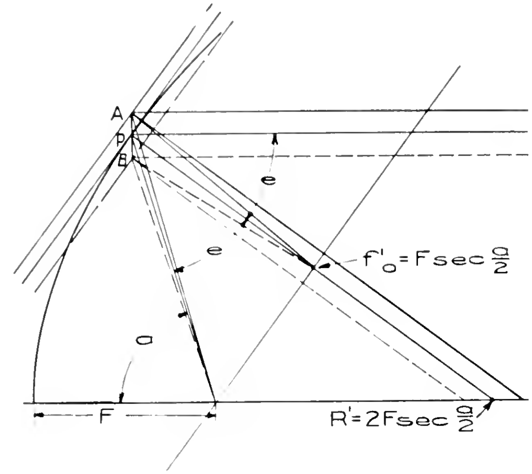


Fig. 2. Focal Properties of a Sagittal Line

If the parallel incident rays, Fig. 1, are rotated until they are parallel to the axis of the parabolic curve, we have

$$2\,e = a$$

$$e = \frac{a}{2}$$

and

$$f_{\frac{a}{2}} = f_0 \cos \frac{a}{2} \qquad (7)$$

and also, if we substitute for f_0 its value in terms of F and $\sec \frac{a}{2}$ as found in equation (3), we get

$$f_{\frac{a}{2}} = F \sec^3 \frac{a}{2} \cos \frac{a}{2}$$

$$= F \sec^2 \frac{a}{2} \qquad (8)$$

which is the length of the radius vector p as defined by the equation of the parabola itself. The focal point of the entire parabolic curve, therefore, lies on the locus of foci of the element $P_1\,P_2$ but it is a secondary or special focus.

A point source of light placed at any point of the circular locus will have such of its light as strikes the parabolic curve at the point of tangency to the circle reflected in a parallel beam. The focus of the parabola acquires its optical importance from the fact that it lies on the common crossing point of *all* the circular loci that may be drawn at different parts of the parabolic curve, and therefore it becomes the principal focus of the parabolic curve taken as a whole.

Sagittal Line

The curvature of a paraboloidal surface is not the same for an elemental line in the surface and in a plane through the axis (the meridian section) as it is for a second line at right angles (known as the sagittal section). This is apparent when we remember what curves are formed by a plane intersecting a paraboloid. If the intersecting plane is perpendicular to the axis the curve of intersection is a circle; if the plane is parallel to the axis the curve is identical with the generating parabola, but of course is shifted to one side of the original axis. A plane that is neither parallel nor perpendicular to the axis intercepts the paraboloid in an ellipse and it is evident that the second, or sagittal, line just mentioned is a section of an ellipse. We might solve for this ellipse and thus find the normal and radius of the element in question, but there is a much simpler way of finding its characteristics.

Every normal to points in a surface of revolution intercepts the axis of revolution, and we may define the radius of sagittal curvature at a point P, Fig. 2, as being the point of intersection of two adjacent normals such as those erected at A and B on a line in the surface at right angles to the parabolic section. The intersection of the normals is at the axis, and the length of a normal to a point on a parabolic curve is

$$R' = 2\,F \sec \frac{a}{2} \qquad (9)$$

where a is the angle between the axis and the radius vector to the point at which the normal is erected. The principal focal length of the sagittal element is therefore half the length of the normal, or

$$f_0' = F \sec \frac{a}{2} \qquad (10)$$

By equation (3) the expression for the principal focus in the meridian plane was found to contain $\sec^3 \frac{a}{2}$ as a factor; and as $\sec^3 \frac{a}{2}$ is always greater than $\sec \frac{a}{2}$ when a is less than 180 deg., the length of f_0 is always greater than f_0'.

If we imagine the parabolic curve and its axis to lie in the plane of the paper, Fig. 2, then point A will be above the paper and B will be below it, and parallel planes can be passed through A and B parallel to the plane of the paper and separated by the distance AB. Pass a plane perpendicular to the above planes, so that it contains the center of curvature R', the principal focal point f_0' of the line AB, and the line AB itself. A pair of rays parallel to the normal and incident at A and B will after reflection intersect at a distance f_0' as found above, and the reflected rays will lie in the perpendicular plane just erected. It is desired to trace these reflected rays and find their intersection as the parallel incident rays are rotated in their respective planes but kept parallel to one another.

At the points A and B erect lines that are perpendicular to both the incident and reflected rays (one line lies in the horizontal plane through A and the other in the horizontal plane through B) and at f_0' erect a common perpendicular to the two reflected rays (this lies in the plane of the paper).

Planes passed through these perpendiculars will pass obliquely between the three parallel planes through A, P and B and the intersection of the two oblique planes will be on the normal through f_0'. As the incident rays are rotated through angle e, the reflected rays will be rotated in an opposite direction through the same angle and as they always lie in the oblique planes their intersection will fall on the intersection of the planes, and the focal length will be

$$f_e' = f_0' \sec e \tag{11}$$

The right-hand member of this equation indicates a straight line as the locus of foci, and in this case the focal length increases with increasing values of e. If we rotate the pair of incident rays until they are parallel to the axis of the parabola we have

$$2e = a$$

and
$$e = \frac{a}{2}$$

therefore

$$f'_{\frac{a}{2}} = f_0' \sec \frac{a}{2} \tag{12}$$

and substituting for f_0' from equation (10) we get the special condition

$$f_{\frac{a}{2}} = F \sec^2 \frac{a}{2} \tag{13}$$

which shows that the locus of foci passes through the focal point of the parabola.

Element of Surface

So far we have considered the optical properties of lines in the surface of the paraboloid, but what of the surfaces as such? In Fig. 3 the two elemental lines P_1 P_2 and AB have been taken to locate and define an element of the reflecting surface. A bundle of incident parallel rays normal to the surface will be reflected into a *line* focus at f_0' and into another *line* focus at f_0 as defined by equations (10) and (3) and these two line foci will be perpendicular to one another (similar to Sturm's conoid). In Fig. 3, P_1' P_2' represent the line image at f_0' that lies on the straight line locus of f_e', and hence it is in the plane of the paper. The light, after passing through P_1' P_2' forms a second line image $A'B'$ perpendicular to the plane of the paper and having its center on the circular locus of f_e. It is evident that as neither $A'B'$ nor P_1' P_2' are common focal points for the two defining lines in the surface of the reflector, neither will do as a location for a source of light to form a parallel beam. If the incident bundle of parallel rays is rotated upward from the axis of the parabola, the focal lines will rotate into lower positions on the straight line and circle, as P_1'' P_2'' and A'' B'', Fig. 3. The two lines are now shorter and closer together, and if the upward rotation is continued until the incident light is parallel to the axis of the paraboloid the focal lines will merge into a point at the

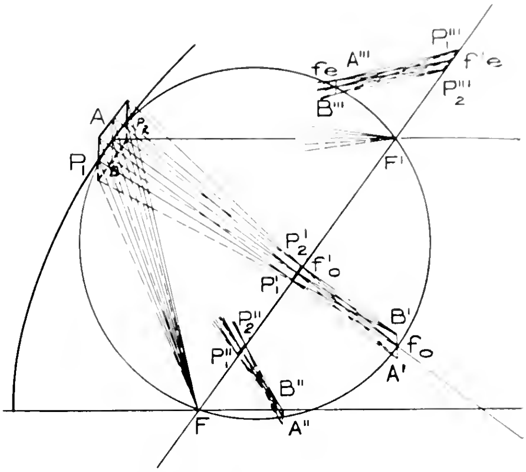


Fig. 3. Focal Properties of Surface Area at Crossing Point of Meridian and Sagittal Lines

crossing point of the circle and the line; that is, at the focus of the paraboloid. Therefore, it is proved that the entire paraboloid will reflect into a parallel beam the light that originates at its focus.

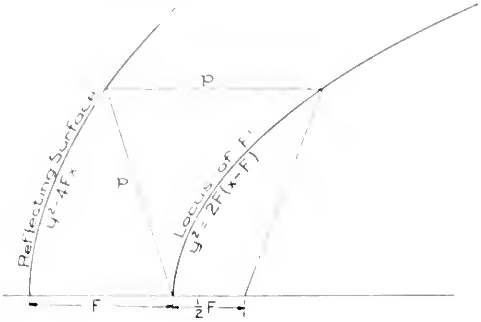


Fig. 4. A Section of a Paraboloidal Surface and the Related Paraboloidal Locus of F′

If the incident parallel rays are rotated downward beyond the focus of the paraboloid, Fig. 3, the focal point will separate into two focal lines as before, except that $P_1''' \; P_2'''$ which has previously been the closer of the two to the reflecting surface now is farther away than $A''' \; B'''$ but they are in the plane of the paper and perpendicular to it just as before.

There is one particular condition that has been found useful in practice without the user always realizing fully just what takes place. The two focal line loci meet at F' and this point has identical properties with regard to the element of surface as has point F. When light from a point source at F', travelling parallel to the axis of the paraboloid, strikes the elemental surface $P_1 \; P_2 \; AB$ it will be reflected in a beam of parallel rays, and this beam will pass through the focus F, so that the two points F and F' are optically symmetrical in one respect, but F' as a source point is limited to a small area while F is general for the entire surface.

Use of the F′ Point

In Fig. 5 is shown a vertical surface illuminated by a parabolic reflector and a lamp near one of the F' positions. This form of beam is ideal for illuminating either a highway or a wall or any rectangular area that must be illuminated from a point well to one side of the center. In the case of a highway the point of the beam, which is the point of greatest intensity, is directed down the highway and the wide section of low intensity is directed on the road immediately in front of the unit.

For wall illumination the unit is set up directly under the section to be illuminated and the beam then covers a vertical section of wall. The form of the beam depends upon the position of the light source on the locus of F'. A short distance from the geometrical focus gives a beam only slightly out of round with the point of maximum intensity shifted

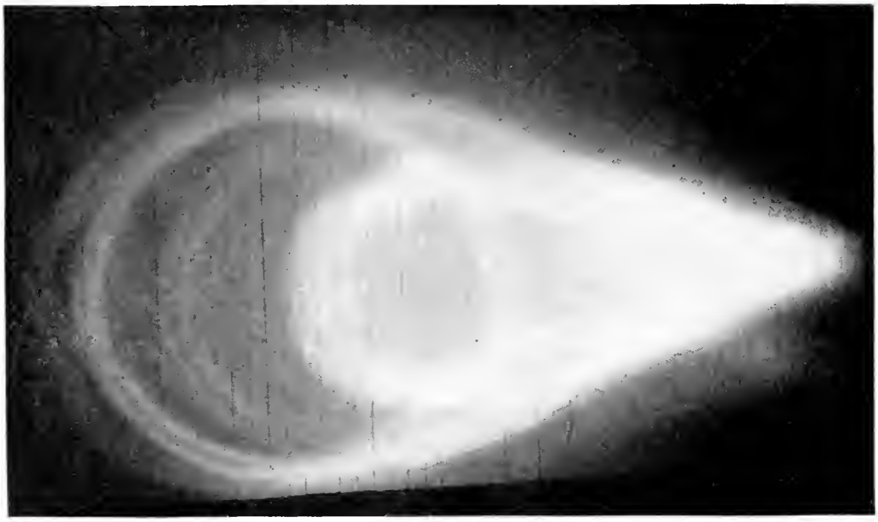
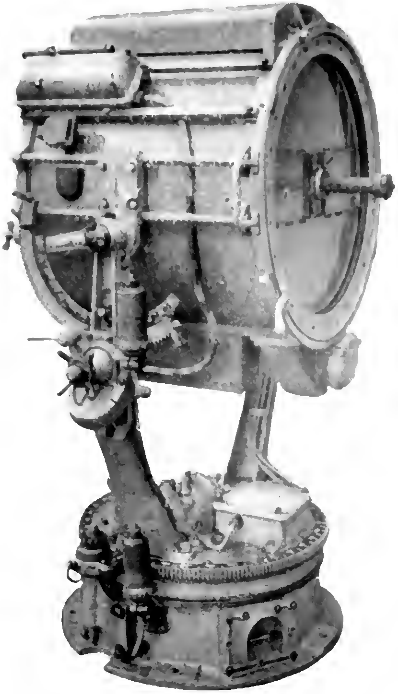
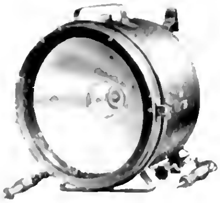


Fig. 5. The Distribution of Light in a Plane at Right Angles to the Axis of Projection when the lamp is near the paraboloidal focal surface is such that the small section of the beam has a high intensity and the wide section a low intensity



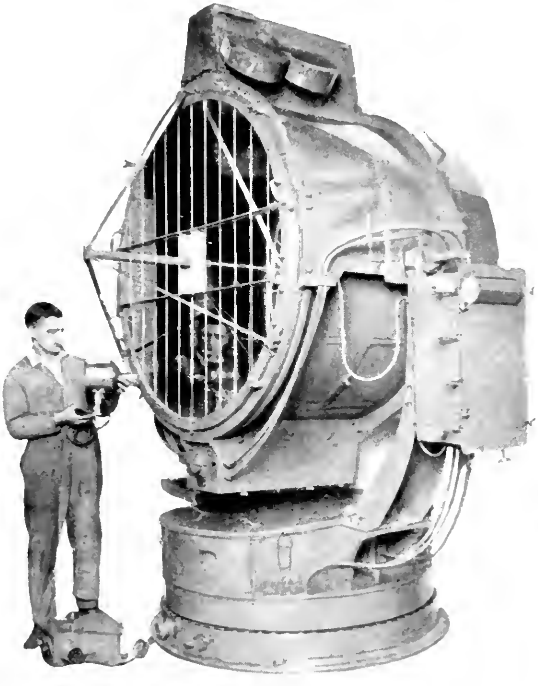
A 24-in. High-intensity Searchlight with a Beam Power of 80,000,000 Candles, Used on Destroyers



Incandescent Trolley Headlight

A "Sunshine" Producer for the Motion-picture Studio

The Special Dome Door with Its Cushion Support Resists the Shock of Salvo Firing on Battleships. The curvature of the glass is such that it does not interfere with the parallel projection of light



This Large Searchlight May be Turned and Elevated by Electric Remote Control. The Small One, held by the man, is Directed by Hand

A Coast Fortification Searchlight of 700,000,000 Candles. The Current is Automatically Maintained Constant and the Crater in Focus

HEADLIGHT, STUDIO FLOODLIGHT, AND SEARCHLIGHTS FOR VARIOUS TYPES OF PROJECTION to near one edge. The beam of Fig. 5 was obtained by moving the lamp about 3 in. from the focal point of a 16-in. dia. 3-in. focal length parabola.

Locus of F′

From the construction of Fig. 3 it is evident that F and F' are equally distant from the reflecting element. In Fig. 4 this relation has been used to construct the locus of all points F' for the entire reflecting surface.

The rectangular form of equation for the parabola is

$$y^2 = 4Fx \qquad (14)$$

and the length of a radius vector is

$$p = F + x \qquad (15)$$

If the coordinates of the point P are x and y, then the coordinates of F' are $x + (F + x)$ and y, or $2\ x + F$ and y.

This leads to the equation

$$y^2 = 2\ \ F(x - F) \qquad (16)$$

for the locus of F'; that is, F' moves along a parabola having a focal length of ½ F and having its vertex at the focal point of the reflector.

It was observed during the tests of which Fig. 5 is a part that for some positions of the lamp there were four active sections of mirror directing light into the small end of the beam sections where the intensity was greatest. The explanation of these four spots is found in the fact that the points F and F' are not isolated positions in space but are merely two points on a closed curve of focal positions that give parallel projections from a given elemental section of the mirror surface.

In Fig. 3 the parallel incident light moves in the plane of the paper and the length of f_e' becomes greater than f_e when either the F position or the F' position has been passed, as at $A'''B'''$ and $P_1'''\ P_2'''$. If now the incident light is rotated in a plane perpendicular to the paper the line $A'''B'''$ will move out in a line perpendicular to the paper while $P_1'''\ P_2'''$ will move in a circular path toward the surface element and $A'''B'''$ and $P_1'''\ P_2'''$ will again come into coincidence.

In Fig. 6a, which is an oblique view of a paraboloidal reflector, $sf_0'\ f_0$ is the normal to the element s, $sFf_0\ F'$ is the circular locus of f_e, and $Ff_0'\ F'$ is the straight line locus of f_e'. The two line images f_e and f_e' come into coincidence again at F'' when the incident parallel light is rotated at right angles to the plane of $sFf_0\ F'$ through the angle g. Coincidence occurs when

$$f_e \sec g = f_e' \cos g$$

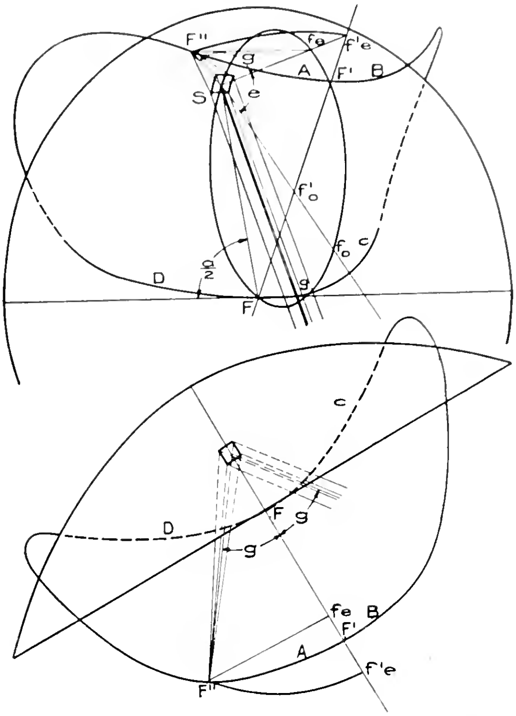
or

$$F \sec^3 \frac{a}{2} \cos e \sec g = F \sec \frac{a}{2} \sec e \cos g$$

$$\sec^2 \frac{a}{2} \cos^2 e = \cos^2 g$$

$$\sec \frac{a}{2} \cos e = \pm \cos g \qquad (17)$$

The locus of equation (17) is a curve on the surface of a cylinder generated by normals to the circular locus of f_e and we may consider this locus to be made up of four branches A, B, C, and D as marked in Figs. 6a and 6b. The four active areas previously mentioned were on the A branch of one area, the B branch of the second, the C branch of the third, and the D branch of the fourth. The light source was between the paraboloidal surface and the focal paraboloid of Fig. 4, and the separation of the areas was decreased as the source approached the focal paraboloid and finally they merged when this paraboloid was reached. The exploration of this space would be an interesting and perhaps profitable task but cannot be undertaken at present.



Figs. 6a and 6b. A Given Elemental Section of a Paraboloid May Be "In Focus" for a Point Source Moved Along the Path of Double Curvature Shown in Projection and Plan. This Path Is Around the Surface of a Cylinder Generated by a Tangent Circle at S Moving Along the Sagittal Tangent

(To be Continued)

The Cooling of Turbine Generators

PART II

HEAT TRANSFER IN SURFACE AIR COOLERS

By A. R. Smith

Construction Engineering Department, General Electric Company

In our December, 1922, issue the author discussed and compared the various methods of cooling air when recirculated. In our present number he discusses "Heat Transfer in Surface Air Coolers." The next article in this series will deal with "Physical Considerations of Surface Air Coolers" and the series will be concluded with Part IV which will discuss "Economics of Using Surface Air Coolers and Heaters in Steam Power Plants."—Editor.

The extraction of heat from air by means of surface coolers or the addition of heat to air by means of surface heaters, when dealing with low temperature differences between the air and the cooling or heating medium, has not been given serious consideration in the past because of the enormous amount of radiating or heating surface required.

Because of the low heat conductivity of air the heat transfer, expressed in the common unit, B. t. u. per deg. F. per sq. ft. per hr., is relatively very poor when compared with values obtainable with steam condensers and other heat exchangers dealing with fluids of high conductivities. The following relative values illustrate the low heat transfer obtainable as encountered in everyday practice when dealing with air or gas.

Steam to Water (Surface Condenser)—400 B. t. u.

Water to Water (Surface Heat Exchangers)—150 B. t. u.

Gas to Water (Fuel Economizer)—4 B. t. u.

Steam to Air (Ordinary Cast Iron Radiator)—1.8 B. t. u.

It is obvious from the above comparison that the high resistance operating against heat flow is on the air or the gas side of the surface. It is a well established fact that the heat transfer improves as the velocity of the air over a surface is increased. If, then, the surface in contact with the air is greatly enlarged and the air velocity is increased by forced circulation, the heat transfer per square foot of surface in contact with the water can be so materially improved that air coolers and air heaters are real commercial possibilities. With the types of coolers considered herein heat transfers as high as 85 B. t. u. per sq. ft. of water surface have been obtained.

Application

The immediate application of surface coolers is to cool the air from turbine generators, thus making it possible to recirculate the air for the purpose of minimizing dirt deposits and practically eliminating fire hazards, as well as the reclamation of the heat of the generator losses. This field is not necessarily limited to turbine generators, but may be extended to hydraulic generators, motors, transformers, and any kind of electrical machinery where air is used as a heat transporting medium.

A surface cooler may be used as a surface heater where it should find much favor if used to heat the air for combustion for stokers, oil burners and pulverized fuel burners. The heating of the combustion air with steam extracted from the main turbine presents the same economic possibilities as the heating of the feed water.

If used as steam condensers, surface coolers will conserve the condensate and make possible condensing operation in localities where no circulating water is available and space limitation is an important factor.

The large amount of surface which can be installed in a small space should in many cases make them well adapted to indirect heating systems.

Construction

The design and construction of surface coolers, as now being manufactured, puts them in the class of other substantial power house apparatus. They should not be confused with automobile radiators but rather compared to surface condensers.

The fins are substantially attached to the tubes. The water passages can be cleaned and the joints between the tubes and the headers can be repaired in the same manner as a surface condenser.

Since each cooler section consists of a bundle of tubes there are unlimited possibilities as to the

Length of Tubes
Arrangement of Tubes
Air Velocities
Water Velocities
Number of Water Passes.

Counter and Direct Flow

Direct flow is the term applied to such an arrangement of air and water passages that the two pass through in the same direction; while counter flow means that they pass in opposite directions, thus bringing the cold water and the cold air at one end of the cooler and the warm water and the warm air at the other end of the cooler. The counter flow principle is essential if the air is to be cooled to a temperature close to the entering water temperature or if the water is to be heated to a temperature close to the entering air temperature.

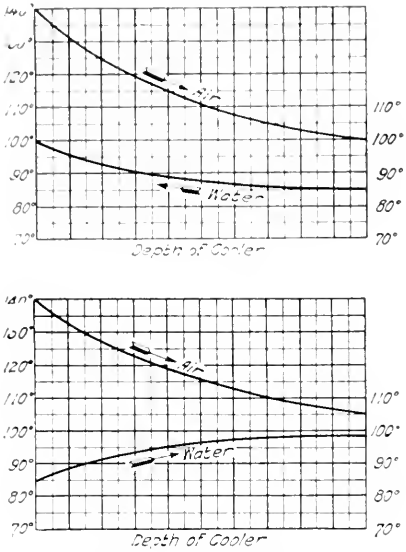


Fig. 1. Curves in Upper Section Show Counter Flow Principle; Lower Section, Direct Flow Principle. Water 85 Deg. F. Air 140 Deg. F.

The difference in effect between counter and direct flow depends on the ratio of air and water quantities and the amount of heat transferred. From Fig. 1, illustrating a representative condition, it will be observed that the counter flow cooler cools the air to within 15 deg. F. of the incoming water temperature, whereas, the same cooler using direct flow cools it only to within 20 deg. F. Also in the latter case the cooler will remove but 88.5 per cent of the heat that it would if used for counter flow.

Heat Transfer

The unit of heat transfer generally used is B. t. u. per square foot of surface per hour per degree F. difference in temperature, and this unit will be used throughout this description. Also when reference is made to the surface area, it means the square feet of surface exposed to the air, that is, it is a measurement of the fin area as well as the tube surface.

In determining the unit heat transfer the mean temperature difference between the air and the water must be determined. Where the temperature change of both fluids is slight the arithmetic mean temperature can be used without introducing much error. But, where the temperature change of either or both fluids is considerable, then the logarithmic mean is far more accurate.

If the ratio of the terminal temperature difference to the initial temperature difference is 1 to 2 the error is 4 per cent but if the ratio is 1 to 5, the error is 20 per cent. The conditions dealt with here show ratios sometimes in excess of 1 to 5 which has necessitated the general use of the logarithmic mean temperature as a basis of all heat transfer calculations.

The heat transfer possible depends on the design and construction of the cooler and there may be many unknown factors as well as the following established factors, which have a bearing on the heat transfer:

Arrangement of tubes
Tube spacing
Material of tubes and fins
Depth of fins
Spacing of fins
Thickness of fins
Attachment of fins
Smoothness of surface
Uniformity of water flow.

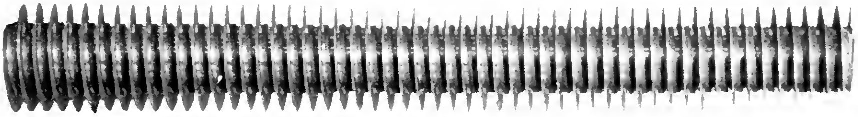


Fig. 2. Brass Tube with Spirally Wound Copper Fins

The heat transfer is also greatly affected according to the utilization of the cooler. The factors which have an effect on the heat transfer are as follows:

Air Velocity
Air Distribution
Water Velocity
Cleanliness of Surface.

Physical Conditions

The characteristics of coolers having different kinds of radiating surface may vary quite widely; but the efficiency of heat transfer on the basis of a square foot of radiating surface on the air side does not change as much as might be expected, provided there is no decided limitation to the transference of heat from the extremities of the radiating surface back to the tube conducting the water.

Many samples were tested to determine if one kind of surface was more effective than another. Most of the samples were of the finned variety and included fins of different depths, thicknesses, spacings, and colors. The type selected consisted of a $\frac{5}{8}$-in. outside diameter, Number 18 B. W. G. Admiralty brass tube with $\frac{1}{4}$ in. deep by 0.012 in. thick copper fins spaced seven to the inch and secured to the tube by flanging and soldering. Such a tube is shown in Fig. 2 and data given herein apply to this particular type of radiating surface.

Effect of Air Velocity on Heat Transfer

The prevailing impression concerning the effect of gas or air velocity on heat transfer has been that the heat transfer varied proportionally to the square root of the gas velocities. It is obvious that no such fixed law can exist because the heat transfer is also affected by the resistance on the water side and therefore unless the relation of internal and external resistances is fixed the effect of air velocity must be a variable factor.

A general average of the effect of air velocity, as indicated from many tests on these coolers (see Fig. 3), shows a proportionality varying from the 0.5 power to the first power of the air velocity and this with a fixed water velocity. When the air velocity is increased, the resistance to the flow of heat on the air side is reduced but the resistance on the water side is unchanged. Consequently, the effect on the heat transfer depends on the relation of these two resistances. If the water velocity were increased so as to reduce the resistance on the water side commensurate with the reduction of resistance on the air side, the heat transfer probably would be directly proportional to the air velocity.

Some investigators maintain that heat transfer is a function of the frictional resistance rather than the velocity and this is undoubtedly true to some extent because a high resistance to the flow of air generally means a more vigorous agitation and impact which is conducive to better heat transfer. However, resistance does not necessarily mean frictional resistance but may be loss of velocity head and severe eddying, which losses probably have no effect on heat transfer.

Effect of Water Velocity on Heat Transfer

The effect of water velocity on the heat transfer will depend largely on the medium to or from which the heat is being transmitted.

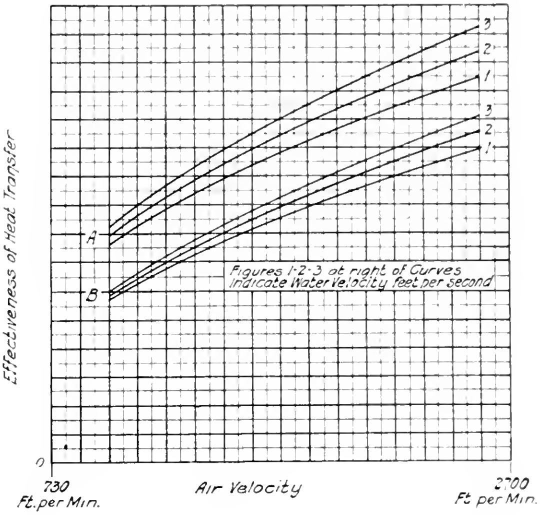


Fig. 3. Effect of Air Velocity on Heat Transfer. Group A, Curves for shallow cooler. Group B, Curves for deep cooler

A more marked improvement would be expected in a steam condenser than in an air cooler because, in the latter case, thermal resistance on the water side is relatively low, compared with the resistance on the air side, and therefore any improvement on the water side will have little effect on the overall results.

In the case of the coolers under consideration, the air surface is six times the water surface, so that the conditions are approaching those met with in steam condenser practice and a reasonable improvement was obtained in the tests. The results are shown in Fig. 4.

If the water velocity in the tubes is below the critical velocity erratic results may be expected. The theoretical critical velocities for $\frac{5}{8}$-in. tubes are as follows. For velocities below these values the flow will not be turbulent, and within the zone it may or may not be turbulent depending on whether agitation has or has not been started.

THEORETICAL CRITICAL VELOCITIES FOR $^5/_8$-IN. TUBES

Temperature	Stream Line Flow Below		Turbulent Flow Above
86 deg. F....	0.4 ft. sec.	uncertain zone	2.6 ft. sec.
68 deg. F....	0.5 ft. sec.		3.1 ft. sec.
50 deg. F....	0.6 ft. sec.		4.1 ft. sec.

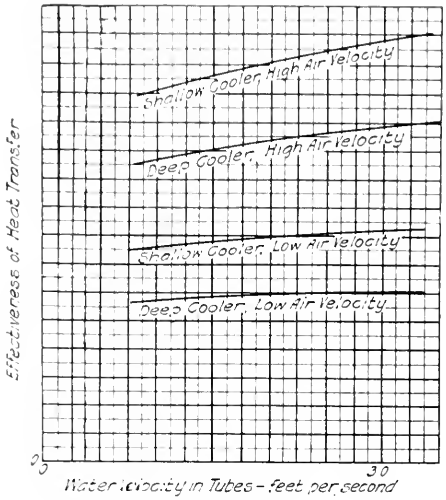


Fig. 4. Effect of Water Velocity on Heat Transfer

Effect of Depth of Cooler on Heat Transfer

A careful analysis of many tests covering different kinds of coolers revealed the fact that the depth of cooler had a decided effect on the unit heat transfer. By depth is meant the square feet of surface traversed by the air, from the entrance to the exit, per square foot of frontal area or per square foot of free area.

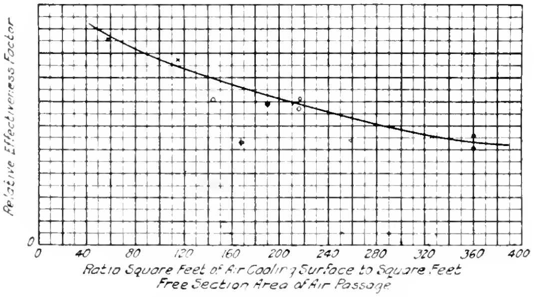


Fig. 5. Relative Effectiveness Factor for Six Types of Surface Cooling Equipment Reduced to 1600 Feet Per Minute Air Velocity and Two Feet Per Second Water Velocity with Estimated Allowance for Tube Design

An explanation of this phenomenon has been sought by attributing it to one or more of the following causes; but in every instance some individual test would disprove the theory:

(1) That the logarithmic mean temperature might not be a true expression of the temperature difference.

(2) That there may be condensation and re-evaporation of moisture in the air because of the water temperature being below that of the dew point.

(3) That the effect of the viscosity of the water and the viscosity of the air may be appreciable.

(4) That there may be variation of heat transfer with temperature difference.

(5) That, considering the low temperature differences, there may be a fixed loss or a fixed temperature difference to produce any flow of heat.

(6) That in combining so much surface into one cooler, there may be a material amount of heat conducted from the high to the low temperature side.

(7) That, because of the relatively large drop in temperature of the air in a very short distance and in a very short period of time, the actual air temperature gradient effecting the heat transfer may be quite different from the gradient expected or the one measured by thermometers.

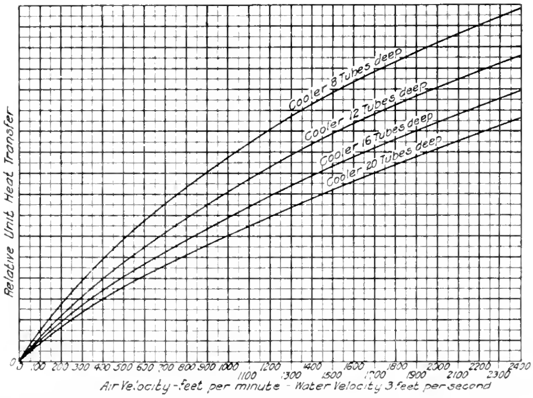


Fig. 6. Illustrating How the Heat Transfer is Affected by Air Velocity and Depth of Cooler for a Constant Water Velocity

This condition has been found by other experimenters to a somewhat lesser extent. The large number of tests made under widely varying conditions were remarkably consistent in all respects and they all indicated a decided falling off in heat transfers as the depth was increased as indicated in Fig. 5. The correct explanation of this condition may be a combination of several of the foregoing effects.

Conclusions

The velocity of air is a very influential factor in heat transfer, but the effect of water velocity on heat transfer is relatively small providing a turbulent flow is established.

The material used, the physical construction, and character of design are important factors in the heat transfer. The depth of cooler must be taken into consideration in determining the overall performance. It is unsafe to assume that the unit performance of a small cooler can be duplicated in a large cooler.

The proper distribution of air and water is, of course, essential. No mention is made of the possible variation which may result from poor distribution, because all test results are of coolers having apparently good air and water distribution.

The determination of cooler depth is dependent on the air velocity. For low air velocities the cooler should be shallow and for high air velocities the cooler should be deep. The curves in Fig. 6 illustrate how the heat transfer is affected by air velocity and depth of cooler for a constant water velocity.

Notes on Wiring

By A. K. Baylor

General Electric Company, New York

Chairman Wiring Department of Joint Committee for Business Development

These notes based on figures and arguments issued from time to time by the Wiring Department show the direction in which the Joint Committee for Business Development is working. The figures given prove what boundless possibilities there are in the electrical field and emphasize the fact that we have hardly scratched the surface yet. The engineer is ahead of the business man. The business man must now get busy and make a more extensive use of what the engineer has developed.—Editor.

Among the various branches of work of the Joint Committee for Business Development, the Wiring Department is just now especially active.

It is generally agreed that the development of the domestic demand offers the best immediate prospect of new business for the central station in most communities. The possibilities in this direction are emphasized by the following figures:

Estimated number homes in United States, approximately	21,000,000
Estimated number homes reached by electric lines, approximately	13,000,000
Estimated number homes wired for electric service	7,600,000
Estimated number homes reached by electric service, *but not wired*	5,400,000
Estimated number homes not reached by electric service, approximately	8,000,000
Estimated number homes connected during 1921	700,000

Eight years ago the estimated average annual revenue to central stations per residence customer was $18—now it is over $25.

It appears reasonable to assume that with the present tendency to make greater use of light and domestic appliances, the domestic revenue within the next five years should be increased to at least $35 per annum. Also that the number of houses connected per annum for the next five years should be at least equal to the record of 1921, or a total of 3,500,000 houses connected during the five year period. Increasing the present average domestic demand from $25 to $35 per annum and adding 3,500,000 homes at a $35 average per annum would yield a total increase of annual gross from domestic load of nearly $200,000,000.

It is obvious that next to the establishment of the central station itself, wiring—the physical connection with the consumer—underlies all central station service and that the central station is primarily interested (with the consumer) in the character and capacity of the connecting lines and the adequacy of outlets.

The central station is the natural nucleus of electrical activity in every community and (neglecting isolated plants) everything electrical in the community is dead and useless except as it is connected to and served by the central station. Therefore in order to get satisfactory and maximum results the jobbers, contractors and dealers must work in co-operation with the central station.

The initiative in connecting new customers or increasing demands on existing connections should come from the central station, but, up to say ten years ago, the bulk of house connections came unsolicited. It is only in more recent years that systematic efforts have been made to attract the domestic consumer and develop the use of current consuming appliances in the home. The results obtained indicate that much more can be done along these lines. In general it has been left to the contractors to solicit as well as execute wiring contracts and as a rule they have competed on a price basis. The public generally is ignorant on the subject and at the same time naturally wants connection and service at a minimum cost.

The consumer can readily obtain information as to the extent and cost of everything he requires in the way of electrical equipment and service except in this all important field of wiring circuits and outlets. Here there are no standards for his guidance.

The inevitable result of these conditions has been that the capacity of lines and number of outlets have been cut down to make possible a low contract price and the myriad outlets from the reservoir of power to the point of application are throttled at the nozzle.

Almost without exception the consumer finds from experience the need of more outlets and the cost of adding them is far greater than would have been the case if proper provision had been made in the original installation. In the meantime the sale of current consuming devices is checked and their use, even when purchased, is restricted sometimes to the zero point by lack of convenience outlets.

It is doubtful if there is a home or place of business anywhere, that is, even in the opinion of the occupant, completely and conveniently wired—a condition which is an object lesson for future wiring business and offers immediate opportunity for development of existing connected load.

With the object of establishing some basis for the guidance of the public in dealing with wiring installations, the Wiring Department of the Joint Committee has been working with the Wiring Committee of the N. E. L. A. who have recommended a so-called "Minimum Standard" suggesting its adoption by Central Station authorities generally. Through the agency of the Joint Committee this standard will be brought to the attention also of architects, builders and contractors for their consideration.

Briefly stated, this standard is a minimum of one lighting and one convenience outlet in any one room and an average of three outlets per room, including lighting and convenience outlets but excluding all switches. In computing this average only parlors, sitting rooms, dining rooms, kitchens, bedrooms, etc., are counted as "rooms." Hallways, stairways, closets, cellars, unfinished attics, etc., are *not counted as rooms* but lighting and convenience outlets in these areas are included in estimating the minimum average of three outlets per room.

With such a standard in vogue the consumer on applying to the central station for information as to wiring his house would not merely be referred to the contractor, but would be advised not to consider anything less than the minimum standard as otherwise he would inevitably be obliged to make additions at a price considerably in excess of what they would cost as a part of the original installation. At the same time information would be given as to value and convenience of adequate outlets. The contractor would give similar advice and thus the mind of the customer would be set in the right direction.

In the case of new building, the architect would base his recommendations on the minimum standard. The result should be a gradual raising of the standard until the minimum is increased to an average of four outlets per room, then five or more with the increased use of light, of portable lamps and domestic appliances generally, and resultant appreciation of the necessity of convenience outlets.

Statistics show that ten years ago 2 to 4 per cent of the total expended on the average home was applied to the plumbing equipment. This has been gradually increased to from 7 to 12 per cent.

Today the cost of electrical installation in the average home is estimated at about 2½ per cent. To raise the electrical standards the central station must take the initiative. There is much to be done along educational lines with the public, the architect, the builder and the contractor, but in dealing with the immediate problem of wiring old houses and increasing the outlets in houses already connected the central station must address itself directly to the public. To do this effectively the full co-operation of the contractor must be gained except in the rare cases where central stations have found it necessary to undertake wiring contracts themselves. Will the contractors take advantage of this great opportunity?

A recent article in *Electrical Retailing* points out that the National Association of Electrical Contractors and Dealers was created 22 years ago as an organization of contractors without contemplating the retailing of electrical merchandise. The words "and Dealers" were added only recently when too many got the idea that all contractors should also become dealers. The association was almost swept off its feet by the merchandising movement of the boom years prior to 1921. The depression of last year and the losses sustained through forced liquidation of inventories caused a reaction. This reaction to the original field of contracting was emphasized at the Buffalo convention of 1921 and in the subsequent activities of the Association has caused a large portion of the members to again direct their attention especially to contracting. This tendency is being augmented by the present widespread interest in wiring under the stimulation of the Joint Committee for Business Development and of the Central Station Interests everywhere.

Those who still continue a retail business should bear in mind that more and better wiring with the provision of adequate outlets must in any case precede a full development of appliance sales.

Coincident with the movement for better wiring conditions have come into general operation financing companies organized to give to the customer, through the contractors, the benefit of time payment terms on wiring installations. This has proved a great stimulant to such business.

In some cases contractors have financed their contracts through local banks but although the ordinary bank interest rates on such cases are low compared with those of the contract financing companies, the bank restrictions are unusually severe and the credit of the contractor in his operating function is limited by these loan obligations.

In many communities central stations have financed these contracts but here also the central station must carry such accounts as a contingent liability and at the same time tie up funds that might be applied to the extension of plant and distribution lines.

There is objection also to central stations entering into a quasi banking business. The most serious objection, however, is that central stations may be forced to take action for recovery against customers delinquent on time payment contract to the detriment of their community goodwill.

It appears better, therefore, for either contractor or central station to turn such business over to companies organized and equipped for this special purpose whose rates are reasonable, and especially those who because of their experience and diversity of operations are in a position to follow the details of collection efficiently, assume the bulk of the risk of ultimate payment and relieve the dealers or central stations of the necessity of being the principals in case of re-possession proceedings. Such accommodations are available in case of old houses being wired for the first time or extension of existing installation and in either case where the owner, whether occupant or landlord, can be dealt with.

With such facilities any contractor of good repute, honest, energetic and competent may secure the capital to turn over any volume of business that he can efficiently supervise.

While the central stations and contractors are at work upon the connecting of old houses and amplifying existing installations, what is to be done to insure that wiring of new houses is of proper capacity and that adequate convenience outlets are provided? Here the aid of the architect and builder must be enlisted.

If the house is being designed and built for the owner's private use it may be almost taken for granted that the mere pointing out of the advantages of modern wiring will insure its adoption.

Where the house is built for sale or to rent the owner is of course primarily interested in the sale or rental price and there is little question that the provision of proper wiring will enhance the demand for any house when the trifling increase in price for sale or rent is considered.

No one would consider it practically economical to omit faucets from bath tubs, sinks or basins because water could be brought in buckets or through a hose from another point. Why then should the installation of electrical outlets adequate in number and convenient in location be the exception and not the rule? It should be to the advantage of architects and builders to consider this subject carefully.

There are many angles to this important and interesting problem of wiring and if the interested parties—central station, jobber, contractor, electrical dealer, as well as the architect and builder—will study it in their mutual interest the result should be to the direct advantage of all concerned.

There is no subject more appealing to the general public than electrical service in the home and proper wiring is the foundation of it.

Control Equipments of the Electrically Propelled Ferry Boats for New York City

By L. W. Webb

Railway Equipment Engineering Department, General Electric Company

It is indeed a tribute to the designers of electric propulsion machinery that virtually the same general scheme of control that has proved so successful on ocean-going merchant ships (such as the *Eclipse*) and naval vessels (such as the U. S. S. *Maryland*) will also fill the exacting requirements peculiar to a ferry boat plying back and forth in congested harbor traffic. The principal points of difference result from the double-ended reversible operation that calls for a motor-driven propeller at each end of the boat and for the unequal division of power between these two motors.—Editor.

The three New York Municipal ferries now being built at the Staten Island Shipbuilding Corporation Yards are to be propelled by a 2300-volt three-phase 3500-kv-a. turbine-driven alternator and two 2100-h.p. induction motors. Each induction motor has two separate windings; a high-speed or full-power winding and a low-speed winding. The control is so arranged that the high-speed winding of the stern or propelling motor and the low-speed winding of the bow motor are connected to the alternator. The low-speed winding is so proportioned that the bow motor will develop power just sufficient to overcome the dragging action of the water on the propeller.

The control equipment, a sketch of which is shown in Fig. 1, consists of a group of contactors mounted on the top of the operating panel.

Control Group

The control group on the top consists of a steel framework on which are mounted nine 2300-volt line contactors, four 250-volt field contactors, current and potential transformers for instruments, and two overload relays for the low-speed windings. The contactors are of the air-break type equipped with magnetic blowouts and are operated by means of a master controller and individual solenoids. For emergency operation, however, the contactors may be opened and closed by means of cam shafts actuated by levers on the front of the operating panel. The insulation of the contactors, mechanically and electrically, is of the type successfully used in railway service and consists of vertical steel rods with wrapped insulation upon which are clamped the conducting parts. This method, as proved by past experience, provides flexible insulation of great mechanical and electrical strength.

With all of the contactors above the panel, the high-voltage and heavy-current-carrying parts are well out of reach of the operator. The contactors are faced so that the arc chutes project over the back of the panel.

Operating Panel

The operating panel is a structural steel cell faced on the front side by a sheet steel plate upon which are mounted all the meters and levers necessary to control the turbine and electric gear. There are on the front of the panel: the master controller with its single operating lever, speed-control switch lever, generator-field rheostat handwheel, control switch, and three levers for emergency manual operation in addition to the instruments, instrument fuses, etc. There are no live parts on the front of the panel. The four motor ammeters are connected so as to give the current in each winding of both motors. There is one instrument which will indicate the temperature of the generator field and another which will give the temperatures of the generator as well as the motor stators. One other special instrument is the excitation indicator. It is connected to the alternating-current line circuit by means of current and potential transformers and gives an indication as to whether the correct generator excitation is being held to give efficient, stable operation at any frequency. The speed of the generator and motors is given by three millivoltmeters, calibrated in revolutions per minute, and connected to magnetos.

Connections

The general scheme of connections is shown in Fig. 2. From the sequence of contactor operation, it can be seen that when going in one direction the high-speed winding of *No. 1* motor and the low-speed winding of *No. 2* motor are used. In the other direction the high-speed winding of *No. 2* motor and the low-speed winding of *No. 1* motor are used. In starting and reversing the boat the high-speed winding of one motor only is

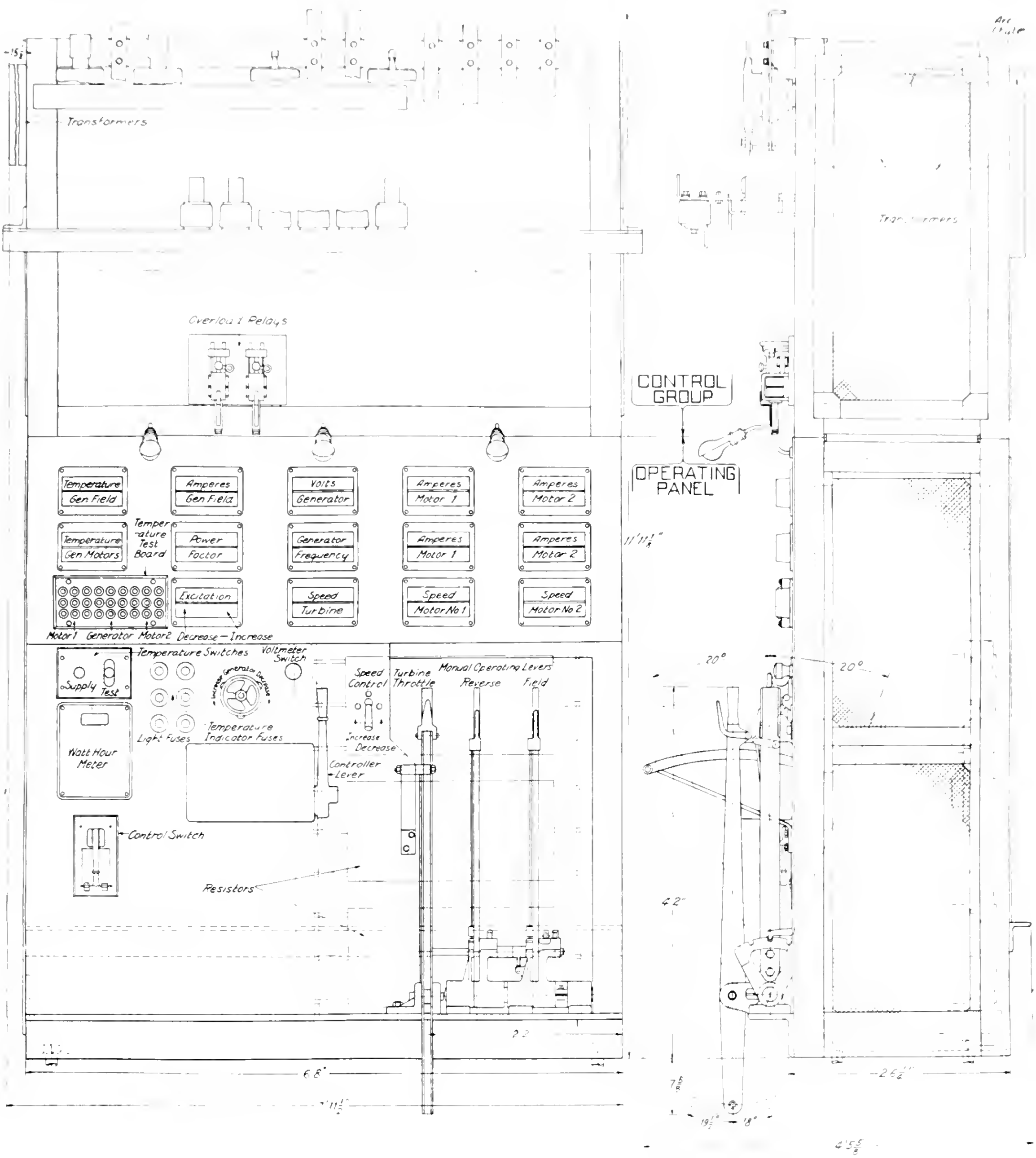
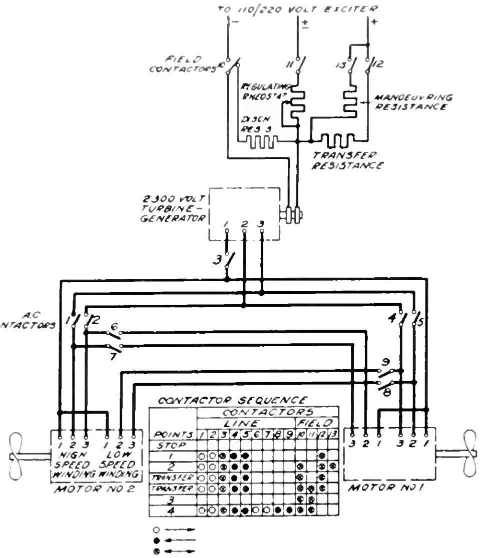


Fig. 1. Outline Drawing showing the Arrangement of the Operating Panel and Control Group

used and always with increased excitation on the alternator. This increased excitation is obtained by contactor *No. 13* closing. As double excitation is not needed the resistance indicated as "manoeuvring resistance" is used. The transfer resistance shown just below is to prevent a short circuit on one side of the three-wire exciter when transferring back to normal excitation without opening the field circuit.

As the bow propeller is very liable to become blocked by running into floating debris, overload relays are arranged in the low-speed windings so that in case this should happen the low-speed winding contactors will be opened.

Although the 2300-volt alternating-current contactors are equipped with magnetic blow-outs capable of opening under load, the control is arranged so that the field contactors open first when taking off power. This is accomplished in the electric control by only the line contactors being closed on the first position. This means that in turning the lever to the *off* position the line contactors are still closed in one position after the field contactors open. When using the manual control the two levers are interlocked so that the field lever has to be turned off first.



POINTS	CONTACTORS												
	LINE									FIELD			
	1	2	3	4	5	6	7	8	9	10	11	12	13
STOP													
1	○	○	◉	●	●							◉	
2	○	○	◉	●	●					◉		◉	◉
TRANSFER	○	○	◉	●	●					◉		◉	
TRANSFER	○	○	◉	●	●					◉	◉	◉	
3										◉	◉		
4	○	○	◉	●	●	○	○	●	●	◉	◉		

○ ⟶
● ⟵
◉ ⟷

Fig. 2. Simplified Diagram of Connections of the Control Equipment

Operation

The master controller has four positions either side of the *off* or *stop* position. The speed-control switch is a three-position switch which controls the direction of rotation of a small motor on the turbine governor and thereby changes the governor setting. It is spring returned to the *off* position from the "Increase" position but a slight star-wheel action will keep it in the "Decrease" position.

To start the boat from rest, after the turbine has been started and the speed-control switch placed in the "Decrease" position, the master-controller lever should be pushed or pulled (depending on the direction it is desired to go) through the first position to the second position. On the second position, connections are established to the high-speed winding of the stern motor and increased excitation put on the alternator. After the motor comes up to a steady speed, the lever should be moved to the third position where the alternator excitation is reduced to normal. Then the lever should be moved to the "Run" position which closes the contactors that connect in the low-speed winding of the bow motor. The speed-control switch may then be manipulated to obtain the desired speed.

To reverse the boat when going at full speed, the speed-control lever should be put over to the "Decrease" position and the controller lever moved to the *off* position, then to the second position in the opposite direction. The procedure from then on is the same as in starting.

If, for any reason, the electric control cannot be used, the contactors may be operated manually by the emergency levers on the right of the panel. It will be noted that there are three large levers. The first or left-hand lever is connected to the turbine throttle. The reverse (second) lever handles the high-speed winding contactors and has a position either side of the *off* position for obtaining reversal of direction. The other lever operates the field contactors and has two positions besides the *off* or *stop* position. In manual operation, the low-speed windings are not used as this is considered emergency operation only.

To start the boat with manual control, the throttle lever should be placed in such a position that the turbine will run between one-quarter and one-third speed. The reverse lever should be placed in either position depending on the direction it is desired to go and then the field lever pulled to the first position which places over-excitation on the alternator. After the motor has come up to a steady speed, the field lever should be pulled over to the "Run" position and the throttle lever moved to give the desired speed.

To reverse the boat when going at full speed, first the throttle should be moved to a point where the turbine will run from one-quarter to one-third speed. Next the field lever should be thrown off after which the reverse lever may be put in the opposite direction. This will change the connections so that the high-speed windings of the other (bow) motor will be used. Then the field lever should be pulled on and the same procedure followed as in starting.

There are mechanical interlocks between the electric lever and the manual levers to prevent both methods of control being used at the same time.

General

Although there is now in operation a Diesel-electrically propelled ferry on the west coast, these New York Municipal ferries will be the first ferry boats to be driven by a turbine-alternator. It is expected that this type of drive will prove to have increased efficiency and flexibility of control the same as has been shown with the Diesel-electric drive and be far superior to the old direct steam drive.

Million-volt Testing Set

PART II

By A. B. Hendricks, Jr.

Transformer Engineering Department, General Electric Company, Pittsfield, Mass.

The design and construction of the three 500-kw., 578,000-volt transformers and of the 500-kw. insulating transformer were given in the December, 1922, issue of the General Electric Review in Part I of this article which included also illustrations of single-phase arcs between sharp points spaced 9, 11, and 14 ft. apart and corresponding to the crest voltages of sine potential waves having effective valu s of approximately 1,000,000, 1,200,000 and 1,500,000 volts.—Editor.

Three-phase Arcs

Photographs of arcs taken with the three main units connected delta-Y with grounded neutral are reproduced in Figs. 19 to 24 inclusive,* the general arrangement being shown in Fig. 19.

The spark gap consisted of sharp pointed brass rods arranged with the points at the corners of a horizontal equilateral triangle, measuring nine feet between points on each side. In these tests there was no neutral arcing point, but the arcs seemed to form indifferently in either delta or Y. Doubtless the Y formation is always preceded by a single-phase arc, but as the arcing voltage between points is closely proportional to distance, at least for high voltages, there is always a strong tendency to form the Y and to the eye it appears

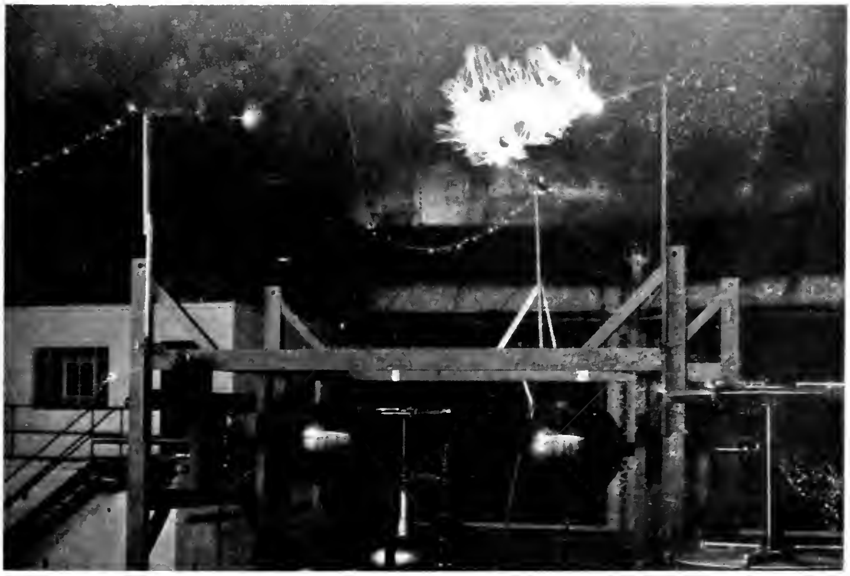


Fig. 19. 1,000,000-volt, 9-ft., Three-phase Spark Gap with Single-phase Arc (One phase reversed)

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* The cover illustration of this issue of the Review is to be considered as included in this group.

instantaneously. Actually there is a million-volt electric field revolving at 3600 revolutions per minute.

The left-hand point in Fig. 19 was connected to the unit placed in the large tank and excited through the insulating transformer as it was inconvenient to change the connections. This inserts additional capacitance and reactance in this leg of the high-voltage Y, thus raising the voltage so that there is a slightly greater tendency to arc from this point to either of the others than for an arc to form between the other two points.

Fig. 20. 1,000,000-volt, 9-ft. Three-phase Arc showing Both Y and Delta Formations

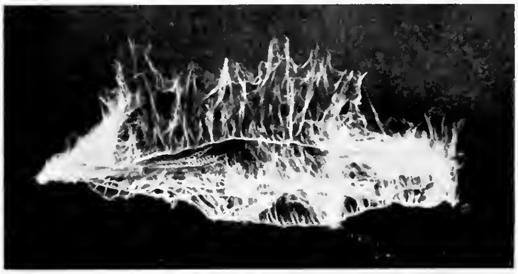

Fig. 21. Another 1,000,000-volt, 9-ft. Three-phase Arc showing Both Y and Delta Formations

In the first test there was no means of determining the polarity of this leg except by trial; and, as shown by Fig. 19, it turned out to be reversed, so that only a single-phase arc was formed between the other two legs.

Reversal of the connections produced the three-phase Y-delta arc shown in Figs. 20 and 21. This is somewhat distorted by being seen nearly edge on from a position below the plane of the spark gap. This was really an open delta-Y arc as there appears to be no direct arc between the two right hand points.

Since the arcs form almost indifferently in any combination, single-phase, open delta, delta or Y, and follow each other in rapid succession, the arrangement shown in the illustration is a matter of chance.

In making the three-phase tests there was no resistance in the high-tension circuit other than the high resistances paralleled by the choke coils.

In Figs. 22 to 24 inclusive* the camera was placed on the floor of the supporting structure shown in Fig. 19, pointing directly upward to the neutral point of the arcs, thus showing them in their natural position and about 10 ft. above the camera.

All the arrangements in taking these last photographs were identical with those of the previous three-phase photographs, but the low-tension voltage was about 10 per cent less, presumably because of different atmospheric conditions. The spacing of the gaps was nine feet as before.

Although less than one million volts were required to start the arc, the generator excitation was greatly increased by means of the field rheostat at the instant of the first discharge so that the actual arcs were formed at an unknown voltage, but approximating one million.

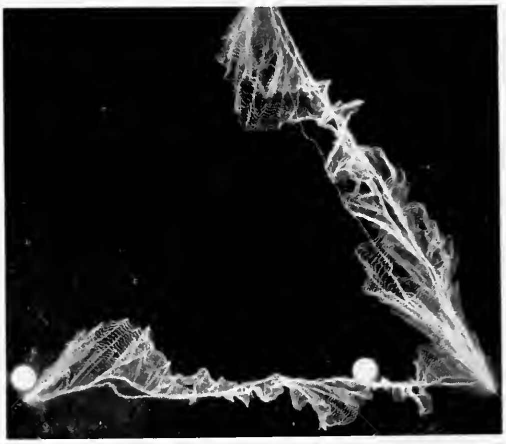

Fig. 22. 1,000,000-volt, 9-ft., Three-phase Arc Forming in Open Delta. The two bright spots are incandescent lamps on the ceiling, which were inadvertently turned on before the camera lens was capped

Unless otherwise indicated, all voltages given in the article are effective values of a sine wave having the same crest value as that actually observed. The generator potential wave form was always close to a true sine wave.

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* The cover illustration of this issue of the REVIEW is to be considered as included in this group.

With all conditions the same as far as known (except for atmospheric variations) the low-tension voltage required to produce the arc, with a constant distance of nine feet between points, varied as much as 15 per cent from day to day and 5 per cent on the same day.

With two units connected in series for one million volts to ground, the high capacitance gives an initial discharge resembling a direct lightning stroke which tends to destroy any object under test. This discharge seems to be a rapidly damped oscillation and is usually followed by a 60-cycle arc.

With one or more units in normal connection, that is with one terminal of the high-tension winding dead grounded, the capacitance effects are less marked but still more severe than with testing transformers of smaller size and less inherent capacitance, and the initial discharge is practically always followed by the 60-cycle arc.

Fig. 22 shows two 9-ft. arcs in open delta, the arc failing to form on the third side. The two bright spots are incandescent lamps on the ceiling which were inadvertently turned on before the lens was capped. The cover illustration of this issue of the REVIEW shows a 9-ft. delta arc, Fig. 23 shows a Y formation and also one single-phase arc, and Fig. 24 shows a series of 9-ft. arcs in both Y and delta.

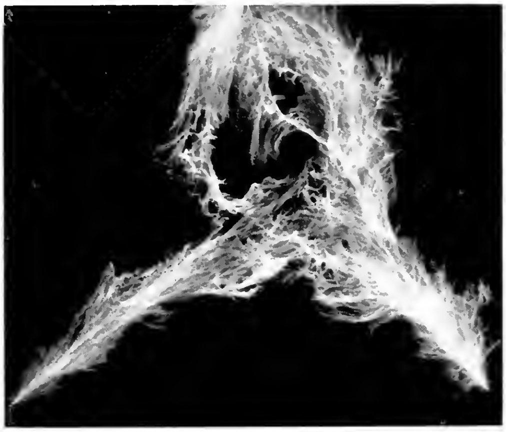


Fig. 23. 1,000,000-volt, 9-ft., Three-phase Arc showing Y and also Single-phase Formation

Three-phase Arcs with Grounded Neutral Sparking Point

Further tests were made with a fourth sharp point placed at the geometric center of the delta and grounded, being supported from above. This caused the Y arcs to predominate, and to restore equilibrium the neutral sparking point was raised about one foot above the plane of the delta. The potential of one point being somewhat higher than that of the others as already explained, it was moved out about six inches in some of the tests. This is the lower right-hand point in the illustrations of three-phase arcs. The curved streak near it is a reflection of one of the balls of the 75-cm. ball gap, which was near the camera as shown in Fig. 19 but not connected to the circuit. No series resistance was used in these tests.

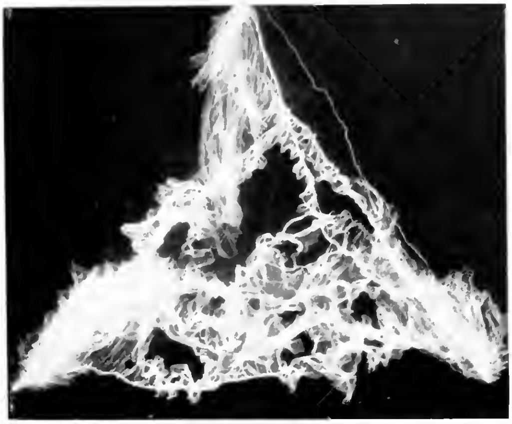


Fig. 24. 1,000,000-volt, 9-ft., Three-phase Arc showing Y-Delta Formation

Fig. 25. Repetition of Single-phase Arcs with Y Arcs Tending to Predominate on Two Legs

Fig. 25 shows single-phase and Y arcs, two legs of the Y tending to predominate. This

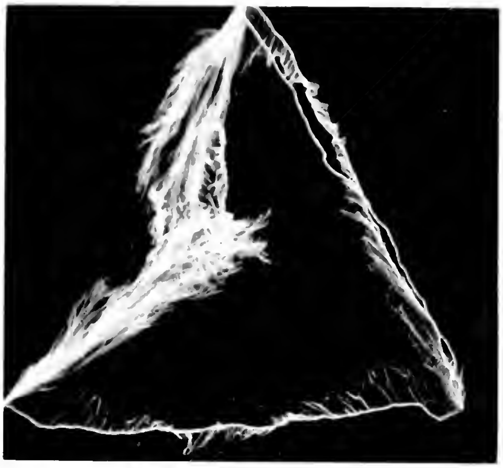


Fig. 26

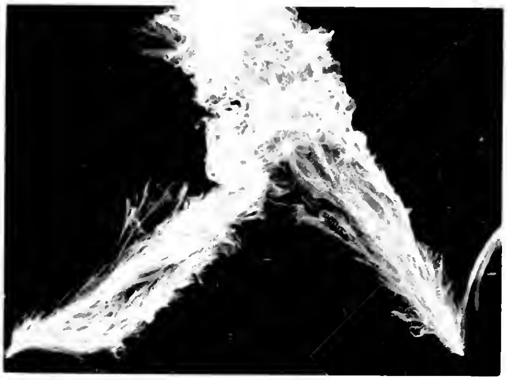


Fig. 27

Fig. 28

was an exhibition arc repeated many times, the arcs holding until they had run up the neutral conductor about 6 ft.

Fig. 26 shows two legs of the delta and two of the Y. The initial discharge of the capacitance (pilot spark) resembles a cotton rope partly untwisted and shows about three oscillations. This effect appears on many of the photographs and justifies the statement that the first discharge is usually oscillatory and rapidly damped. Theory indicates the same thing.

Fig. 27 shows both single-phase and Y arcs and Fig. 28 is a good imitation of the Scott connection.

In Fig. 29 one transformer failed to arc, but a discharge occurred from the neutral to the middle of one side of the delta. The oscillatory character of the initial discharge is clearly shown.

Fig. 30 shows arcs from neutral to two corners only. The grounded neutral sparking point was removed for the next two illustrations.

Fig. 31 gives three single-phase arcs and a Scott connection. Compare with Fig. 28.

Fig. 32 shows a peculiar formation of great beauty. The arcs are doubtless extremely sensitive to atmospheric conditions, the path of the circuits and the proximity of conductors, especially if grounded, and naturally show infinite variety of form.

Tests on Line Insulators

In these tests two transformers were connected in series for 1,000,000 volts to ground. No series resistance was used.

Fig. 29

Fig. 33 shows a 60-cycle arcover to ground on a string of 20 Hewlett insulators, a distance of about 10 ft. at about 950,000 volts. The arc went wide of the insulators, even farther than appears from the illustration.

Effect of Parallel Reactance in Low-Voltage and Series Resistance in High-Voltage Circuit

It has been shown that these transformers take a leading exciting current at a power-factor of about 27 per cent which remains nearly constant through the whole range of voltage.

In a certain test on suspension insulators the generator current was 97.5 amp. and the field current 16 amp. This is an abnormally low field current, the excitation being produced largely by armature reaction of the leading current. The voltage is therefore unstable and at the instant of arcover, when the load changes suddenly from leading to a short-circuit lagging current, the generator voltage suffers a large drop. It was thought that the addition of a constant large lagging load in parallel on the low-voltage side would stabilize the voltage since a much higher field excitation would then be required for the same generator voltage.

Accordingly a power limiting reactance (without iron) of 11.5 ohms was connected across the loaded phase and the test repeated. This reduced the generator current from 97.5 to 34.5 amp. and increased the exciting current from 16 to 35 amp. The arc then held somewhat better. The reactive load stabilizes

Fig. 31

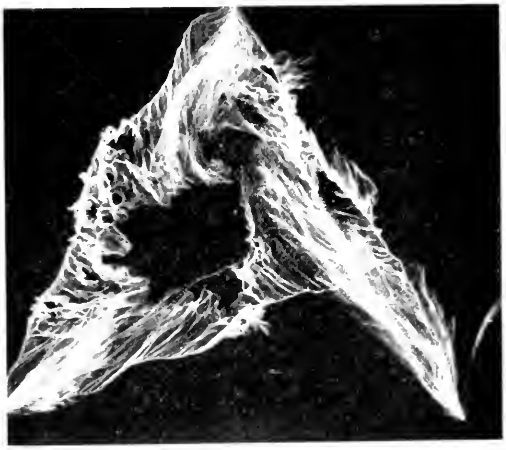


Fig. 32

Fig. 30

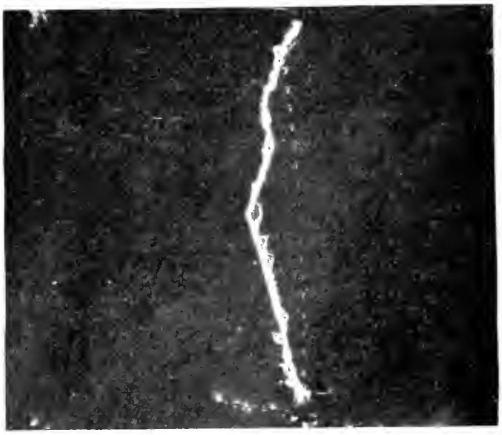


Fig. 33

the generator voltage but does not decrease the destructive effect of the first discharge.

A resistance of 120,000 ohms, consisting of 28 carborundum rods, was then hung from the insulator string and connected in series with it, the reactance being disconnected.

The resistances arced over, as well as the insulators, but the arc failed to hold.

Finally, the reactance and resistance were tried together, the reactance in parallel with the low side, the resistance in series with the high side. The initial discharge, while arcing over the resistances as before, as well as the insulators, was followed by a heavy 60-cycle arc around the insulators, the 60-cycle current also passing through the resistance after the first impulse. No photographs were taken of these last two tests.

In all of these last tests there was little variation in arcing voltage. Apparently the action may be made anything desired by variations in circuit constants and it is a question which condition is most suitable for a given test.

The same transformers will give an impulse test, a 60-cycle arcover, or a combination of both, but the last is much more severe than the usual tests of past experience.

It should be remembered that the actual voltages are not only greater, but also higher to ground and therefore approach more nearly to abnormal service conditions.

The two transformer units have a combined capacity of 1000 kw. at 6 per cent reactance (plus the insulating transformer) and very high internal capacitance, so that extraordinary effects are just what should be expected.

The three-phase nine-foot point spark gap test was repeated with 23 ohms reactance across each low-voltage winding and it was found that the 60-cycle arcs held better than without reactance, which confirms the single-phase results.

Perhaps the effect of capacitance could be modified and controlled by the use of a water jet or other suitable resistance between line and ground.

Wave Forms

The two generators are on the same shaft and while each is rated 500 kw. single-phase, it is wound three-phase Y-connected and is good for 750 kw. three-phase.

With the two generators in parallel the normal capacity is thus 1500 kw. or the same as for the three main transformers connected three-phase. These generators were especially designed for a sine voltage wave, and the variations therefrom are small over a wide range of conditions.

It is often stated as a general rule that a leading current distorts the wave form more than in-phase or lagging currents. This may often be true but as a general statement does not hold; it depends on the design of the generator.

With the reactance in parallel and 34.5 amp. lagging armature current, the amplitude factor (ratio of crest to effective value) of the voltage wave was 1.399.

Without the reactance and with 97.5 amp. leading armature current, this factor was 1.395. In both cases the variation from sine shape was thus about 1 per cent. The wave form was nearly perfect with no appreciable ripples, but more symmetrical with leading current.

The reactance of the main transformer is 6 per cent, the errors of the voltmeter coils at full load, zero power-factor leading, is under ½ of 1 per cent and of the order of 1/10 of 1 per cent under the conditions of the tests described, while for a single transformer at least there is a difference of only about 1 per cent between voltages determined by the conversion ratio and the voltmeter coil. The values of high voltages given herein are as referred to a ball spark gap which responds to transients of extremely short duration, and the difference between the conversion ratio and gap voltages is as follows, in round numbers at full voltage:

7 ½ per cent for one transformer.

17 ½ per cent for two transformers, neutral grounded.

22 ½ per cent for two transformers, one end grounded.

In all cases the ball gap indicates a higher voltage than the conversion ratio or voltmeter coil.

The differences cannot be accounted for by variation of generator wave form (1 per cent), by errors of conversion (1 per cent), or voltmeter coil (1/10 of 1 per cent), nor by errors of instruments or observation. The cause may be transient voltages which are always present and whose effect seems to increase faster than the voltage and thus reaches a high value with the extreme potentials under consideration, or resonant conditions in some part of the circuit.

In referring to test voltages it is therefore pertinent to ask, what voltage? as it may be the average, effective, crest, or transient value that is meant.

There is also a difference in transients. The point gap does not respond as quickly as the ball gap and may indicate less than the maximum instantaneous voltage. In the present series of tests with point gaps the voltage was checked by a 75-cm. ball gap up to 650,000 volts to ground and 950,000 volts with neutral grounded which was as high a voltage as the old spark gap would stand, the new 100-cm. gap being unfinished.

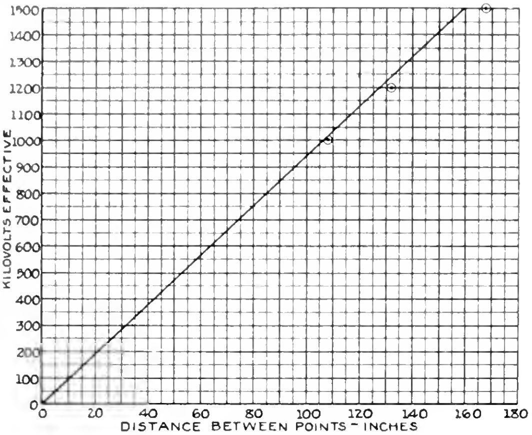


Fig. 34. Comparison of Test Results, 1,000,000, 1,200,000, and 1,500,000 Volts at 108, 132, and 168 inches, with Tentative Straight-line Spark-gap Calibration Curve Through the Origin and 1,000,000 Volts at 106 inches

The point-gap distance-voltage curve has been determined with some accuracy up to 1,000,000 volts (106 inches) and being close to a straight line through the origin of co-ordinates could be produced to 1,500,000 as a first approximation at least. This also could be checked by the ratio of ball gap to the conversion voltages of a single unit.

Fig. 34 represents a tentative calibration, a straight line from the origin through 106 inches at 1,000,000 volts as previously determined by F. W. Peek, Jr. The three plotted points correspond to those of this article at 108, 132 and 168 inches (9, 11 and 14 ft.) for 1,000,000, 1,200,000 and 1,500,000 volts respectively and are given simply to show that the stated voltages were actually reached and probably exceeded.

The point gap is variable in behavior, the results depending largely on atmospheric conditions, but the curve given is probably correct within 5 per cent. It does not hold for small spacings below 100,000 volts.

The transformer terminals act like ball gaps in not showing corona and in response to transients so that the latter set a limit to the voltage that may be obtained. As far as the transformer proper is concerned it could evidently be operated at still higher 60-cycle voltages if the transients could be suppressed

In one instance, already referred to, a discharge occurred from the choke coil on the million-volt terminal about 18 ft. due west to an iron pipe on the wall of the building, although a sparking point was mounted on the same choke coil nine feet from a grounded point due east. The west gap resembled a point and plane, the east gap was composed of two points, which may explain the tendency to arc to the west.

In one of the three-phase tests with the three units connected in Y with grounded neutral, one of the terminals arced over from cap to sleeve after a vicious series of 9-ft. arcs across the three-phase point gap at about 1,000,000 volts. Two of the terminals measure 65 in. from cap to sleeve, the third or million-volt terminal mounted in the large open tank measures 125 5/8 in. This unit was also grounded, but excited through the insulating transformer, the additional reactance and capacitance raising the voltage, though but slightly. However, this terminal arced over, the two shorter ones of about half the length did not!

It has been found that the results may be greatly improved by taking the precaution to keep the generator excitation as high as possible. This is not on account of wave form, which is always good, but to stabilize the generator voltage to give sufficient power to cause a 60-cycle arc to follow the initial oscillatory discharge. In some of the tests, such as on suspension insulators and high-voltage bushings, the 60-cycle current failed to follow the initial discharge, the latter being oscillatory and of destructive violence. The simple expedient of changing the generator connection for a lower voltage, which enables much greater exciting current to be used, was sufficient to insure that a 60-cycle arc of great volume would invariably follow the first discharge. This also seems to have a tendency to suppress the oscillations and reduce the destructive effects.

It is therefore concluded that with the present testing set at least, high generator excitation is of great importance.

Fig. 35 shows a three-phase point-spark gap with 10 ft. 2½ in. spacing, arcing in T-formation at over 1,000,000 volts with low generator excitation. The crests of the current waves show as fine separate lines. Fig. 36 is of another arc at over a million volts taken under the same conditions except with high

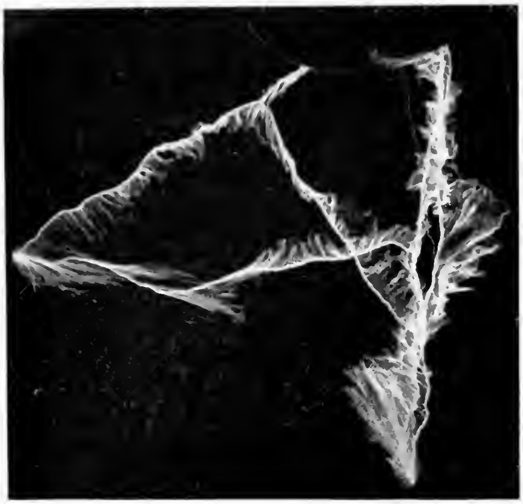


Fig. 35. Three-phase Arc Between Points 10 ft., 2½ in. Apart. Generator under-excited, giving arc of little volume

Fig. 36. Three-phase Arc Between Points 10 ft., 2½ in. Apart. Generator over-excited, giving arc of great volume

generator excitation. This arc is of much greater volume and appears as a continuous flame.

This is a record of some of the first results obtained with the new testing set representing the first trials which were in the nature of routine acceptance tests. The principal constants and the characteristic curves were measured with care, but no attempt was made to obtain great accuracy in the arcing tests. When the 100-cm. ball spark gap is put into service it will be possible to extend the spark gap curves with precision to the limit of the apparatus. This is shown in Fig. 37 as it will appear when swung flat against the wall for cleaning and zero adjustment.

It will now be feasible to carry out an unlimited series of tests and researches in a region of high potential yet unexplored, but this must be left for the future to record.

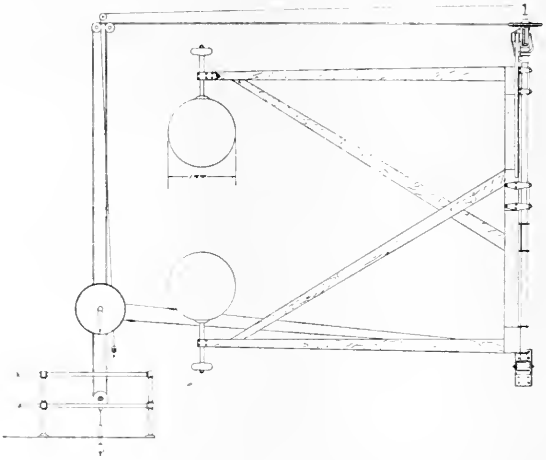


Fig. 37. Diagram of 100-cm. Ball Spark-gap Which Will Make Possible the Extension of Spark-gap Curves with Precision to the Limit of the Testing Set Described in this Article

The Electric Power Industry

PART III

THE MUNICIPAL ELECTRICIAN AND THE ELECTRIC POWER INDUSTRY

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

After tracing the early history of electrical power plants to the time when electric power production and supply became a separate industry the author shows the place held by this industry in our modern industrial life and outlines the probable future trend in the growth of large systems. He then discusses the relationship between the electric power industry and the municipality.—Editor.

The rapid development of electric light, railway and power distribution has placed new duties and new responsibilities on the municipal electrician, varying from the operation of a municipal lighting plant, to advising the legislative body on the rules and regulations required to supervise the operation of a private lighting or railway plant. Before discussing these relations, it may be of interest to briefly review the development of the electric power industry. It started with small local electric lighting stations supplying electricity for domestic lighting and street lighting and later also for small distributed power, and still more recently for all kinds of domestic service, as cooking, heating, ventilation, domestic power in the washing machine, vacuum cleaner, ice cream freezer, etc., though this field of domestic electric service is still little developed in most locations. The electric railway came next, again a local electric plant operating the street cars and in the large cities later on the rapid transit system. At the same time the electrification of the industries started and made rapid progress, operating the machinery of factories and mills by electric motors, often in connection with long distance transmission from water power, but often also from local steam electric plants in the factory or mill.

Thus we once had in the same territory three kinds of electric plants, for lighting, for railway, and for industrial power. This was inefficient and uneconomical. The three uses of electricity do not coincide in time—though they partly overlap—and by combining electric power generation for all classes of work, a better load factor of the plant is secured. That is, the machines are more uniformly loaded, thus operating at better efficiency and less machinery is required. The multiplication of reserve machines, of the operating staff and attendance, etc., is eliminated by consolidating the various small stations into one large station; large and therefore more economical machines become available, etc.

This consolidation was initiated by the development of long distance transmission from water power, by replacing local smaller generating stations by substations from the transmission line. The economies realized herein led to the same development even where steam was the source of power. Two features contributed. First, the development of the modern steam turbine, which reached efficiencies of power production undreamed of in the days of the reciprocating steam engine; but it realized these efficiencies only in the huge units of 10,000 to 50,000 horse power. The second feature is the following: energy or power is the necessity of every industry, and therefore in the days before electrification every factory or mill had its steam engine producing the required power. But power production is an industrial operation just like the production of shoes, or furniture, etc. Now the superior efficiency of modern industrialism is due to the subdivision of work, whereby each industrial operation is carried on by a separate organization. It therefore is not economical to combine two such different industrial operations as the making of furniture and the production of the power used in furniture making; the management of a hotel and the operation of the electric plant supplying light and power to it; the organization most efficient to make furniture will not be efficient to produce power; the efficient management of a hotel will not be efficient in managing an electric plant. This led to the segregation of the power production from the industrial operations using the power, and the concentration of the power production as a separate industry, the *industry of electric power production and supply*.

There are two fundamental necessities of our civilization: materials and power. The supply of materials has been organized during the last century by the development of railroads, steamship lines, etc., so that now anything produced anywhere in the world is available to us, and even in the necessities of life we draw on far distant countries. Today we see the organization, by the electrical engineer, of the second necessity, power; and just as during the last century the country has been covered by a network of railroads, bringing materials from anywhere to anywhere, so now we see the country being covered by a system or network of electric transmission lines, carrying power.

The development is not yet complete, and there are still numerous gaps, but a number of such electric systems already cover and serve territories of 10,000 to 20,000 square miles, and more, with amounts of energy reaching high into the hundred thousands of horse power. More and more these territorial systems interconnect with each other into still larger systems, closing the gap between them, and rapidly develop towards one unified electric power supply system covering the continent. (Though obviously the different parts of a system may be under different ownership, just as different parts of the railroad system are under different ownership.)

Such a modern territorial system interconnects numerous electric generating stations and many users of electric power: cities, industrial establishments, factories and mills, mines, railroad power substations, etc. Some of the generating stations are water power stations; others are steam turbine stations located at strategic points, such as cities or other large users. Sometimes the system centers around, and is developed from, a big city like Chicago or big water power like Niagara; usually, however, the generating stations and the users of power are fairly distributed over a territory (California, New England, Michigan, Central New York, Southern Atlantic States, etc.).

The electric industry thus has outgrown the limits of the municipality and even of the state, and is rapidly becoming a national industry, just like the railroads are.

In general, therefore, it is not economical any more to generate electricity for some limited service by a local station, but it is preferable to buy the electric power from the territorial power systems, even where large amounts of power are needed. Thus for instance the elevated railroads of Chicago have shut down their generating stations—each large enough to supply a good sized city—and buy their power from the Commonwealth Edison Company. The large modern electric station built by the N. Y., N. H. and H. R. R. to supply power for its electrified railway service, stands idle and power bought from the New York Edison Company pulls the trains.

Thus with the development of the electric power industry, a complex situation has arisen, with which the municipal electrician has to cope. It is no more merely the question whether a municipal plant would be preferable, or a local private electric lighting company. The situation is further complicated because even most electrical engineers and administrators do not yet realize it.

There are various new possibilities between the municipal lighting plant and the city buying the electric service from a private electric plant just like any other customer.

Furthermore, new questions arise such as that of the right of transit of high voltage high power circuits over municipal territory to supply power to industries, that of permissible primary distribution voltage, questions of regulation, of reliability of service, etc.

Usually a privately owned public utility corporation supplies the electric service of the municipality. This may operate a local isolated electric generating plant, where the municipality is not yet within reach of a territorial power supply system. Or the municipality may be served from a substation of a territorial system (through transformers for light and power distribution, converters for railway service). Or, where the local station is sufficiently large and modern, it may be tied into the territorial system, so that the municipality becomes one of the customers, the local plant one of the generating stations of the territorial system.

The territorial power company may then operate the local light and power distribution as a part of the territorial system. Or a separate sub-company may be formed to take care of the local distribution, as is often the case, since the problems of local light and power distribution are sufficiently different from those of territorial bulk power distribution to make a separate management advantageous. Or an independent local company may buy the power in bulk from the territorial system and locally distribute it.

For instance, the company which operated an isolated generating station may, when the municipality comes within reach of a territorial system, abandon its local station and buy the power from the territorial system, but otherwise retain its independence.

Usually, the municipality buys its electricity from the local private station or substation. Street lighting is taken care of by a separate contract, as the long hours and the uniform power demand of street lighting justify a lower rate than for domestic lighting, while on the other hand, the street lights and their method of operation are materially different from domestic lighting, requiring considerable special apparatus (constant current transformers, rectifiers, arc lamps, separate circuits, etc.). This has occasionally led to an unfortunate situation resulting in unsatisfactory street lighting by antiquated types of lamp, where the municipality refused to make a contract for more than a year or two, while the street lighting company could not afford the large investment of modernizing the street lighting system without the assurance that the new plant would be in service for a sufficient length of time to return the investment. A possibility is that the municipality does its own street lighting, installing, owning and operating the lamps, the street lighting circuits and the transforming devices, but buying the electric power in bulk from the local or the territorial private corporation (as in Milwaukee, etc.). In general, however, in most municipalities the amount of street lighting is probably too small to economically justify this.

Electricity for indoor lighting of municipal buildings, schools, etc., and for domestic power, as ventilation, would be bought by the city from the public utility corporation at the same rate as by other private customers. Or the city may get a special rate in view of its peculiar position as the giver of the franchise. Or the city, while paying nominally the same rate as private customers, may effectively get a lower rate, for instance by combining the lighting service of all municipal buildings in one bill, and so getting the lower rate of a large customer; or by charging one uniform power rate for all uses, indoor lighting, power, etc.

Occasionally, municipalities may buy large amounts of power for the operation of a municipal pumping plant, etc., at the low rate of industrial bulk power, and sometimes a still lower rate may be secured if—for instance by the use of a reservoir the use of power can be limited to the off peak period, that is, discontinued during the few hours of heavy load on the station.

Theoretically, a municipal plant cannot economically compete with electricity supplied from a territorial system, since even in large municipalities the electricity demand is so much smaller and so much less diversified that the economy of electric power production of the huge modern territorial system cannot be approached. Practically, however under special local conditions a municipal plant may be very successful, especially as long as no supply from a territorial system is available. A municipal plant has the advantage that a municipality usually can borrow money at a lower rate than a private corporation, and as a material part of the cost is the interest on the investment, this results in lower cost. Also, the municipal plant is not intended to make profits. Furthermore, by combination with other municipal activities—as water supply—economies are possible which are not available to a local private plant. The foremost disadvantage of the municipal plant is the political control of our municipalities, which leads to lack of continuity and often inefficiency of the management and the operating force of the plant, and continuity and efficiency of management and operating force are most essential in an electric plant and their absence fatal. Where therefore the local conditions are such as to give continuity to the management of the municipal plant and sufficient independence to train and maintain an efficient operating force, the plant will be successful as long as these conditions pertain.

Industrial power, that is, power in large bulk for the operation of factories, mills, steel plants, etc., can rarely be supplied from the municipal plant, as its size is not large enough to allow sufficiently low rates. When therefore the municipality is reached by a territorial plant, the latter would supply industrial bulk power and in the interest of the local industries access within the municipality would have to be given to the lines of the territorial plant.

The same economic question arises between the municipal plant and the territorial system which arises between a local private generating plant and the territorial system, and which in the latter case has almost always been answered by the local plant tying into the territorial plant as substation or generating station.

The municipal generating station may be replaced by a municipal substation of the territorial plant, that is, the municipality buys the power in bulk and distributes it as light and power. Or, where the nature of the municipal plan warrants it, it may tie in with the territorial system as combined substation and generating station. In short the municipal corporation takes the same relation to the territorial system as the private local distributing company discussed above. Industrial power, and railway power, then may be supplied either directly by the territorial system or by the municipal corporation as its local representative.

Sometimes the development might be carried still further to private operation of the municipal plant. That is, the generating station or substation and the distributing system would be owned by the municipality, but operated by the private territorial company or a sub-company of it.

In general, it must be conceded that the development of the electric power industry from local to national scope leads away from the economic desirability of the municipal electric generation and rather towards municipal supervision and control.

The two features of electric supply which are of foremost importance to the public are regulation and reliability.

In lighting, 1 per cent variation of voltage gives about 5 per cent variation of light. A variation of about 2 per cent in light is the lowest which can be detected by the eye when watching for it, and 5 per cent variation is scarcely appreciable unless continuously recurring as flicker. Even an occasional 10 to 15 per cent variation of light (that is, 2 to 3 per cent voltage variation) is only slightly annoying if not too frequent.

Thus unsteadiness or flickering of the light is only objectionable, and inefficiency is due to continuous low voltage; but aside from this, there usually is little difficulty in maintaining good regulation. The free lamp renewal, practiced by the more progressive lighting companies, is a strong inducement to the company to maintain good regulation, as the life of the lamps decreases and the cost of renewal to the station therefore increases with poor voltage regulation.

More unsatisfactory is the situation regarding reliability, that is, continuity of electricity supply, as the meaning of "reliability" is very vague. For instance, a big metropolitan system claims as evidence of reliability that the power has not been off the busbars of their station for 18 years, while a transmission system claimed as evidence of reliability operation with not more than 13 shut downs, each for a few minutes, during one year.

It would therefore be very desirable if some authoritative body, such as the National Bureau of Standards, would take up the definition of reliability of service, so as to assure that when speaking of reliability different people mean the same thing.

Obviously, the reliability of operation should be as high as possible. There are limits, however, beyond which the further increase of reliability results in a considerable increase of the cost of electricity by the required reserve plant and the question arises, whether, when and how far the increase of reliability justifies the cost. In a metropolitan city, with thousands of elevators full of people liable to be left hanging between floors by the failure of the electric power, with hundreds of crowded assembly places plunged in darkness with the danger of a panic, the highest reliability of electric service is worth far more than in a smaller municipality, where an occasional short shut down means merely an annoyance to the customers. Thus in the latter case, a few shut downs during the year, of short duration, would be justified, if their elimination or reduction would materially increase the cost of service. Thus it is an economic question, depending on local conditions how far increase of reliability is justified. This obviously assumes that the reliability has already by careful management and supervision been carried as high as possible with the existing plant.

The standard system of distribution for electric light, power and other domestic service, which we find in most municipalities, is an overhead 2300-volt (approximately) primary distribution to transformers located on the poles, reducing to the secondary three-wire distribution system of 115/230 volts. Here 115 volts represents anything between 105 and 130 volts, and 2300 volts the voltage corresponding thereto.

Occasionally three such 2300-volt primary circuits are combined by having a common return wire, which often is grounded. By making the three circuits of three phases, the common return carries little or no current. This gives the four-wire, three-phase primary distribution, with 2300 volts between outside wires and neutral, and therefore $2300 \times \sqrt{3} =$ 4000 volts between outside wires. It is often called 4000-volt primary distribution. Its advantage is that a much larger territory (about three times as large) can be covered from the same station and it therefore finds increasing use in large cities and in extended but sparsely populated territories by reaching more customers from the same substation.

Of bearing on the question whether or what limit should be placed on the voltage permissible in overhead lines in municipalities are the primary distribution voltages of 6600 and 13,200 which are being used with increasing frequency in some localities, because it is not economically possible to take a small amount of power from a high voltage transmission line of 60,000 volts and over. The smallest size of wire which can be safely used mechanically in a transformer carries a current which at high transmission voltages represents considerable power and a transformer for less power than this would be practically as large and expensive. Furthermore circuit breakers and lightning protective devices cost almost the same for a small as for a large substation. Thus there is a minimum power below which a substation from a high voltage transmission line is uneconomical. In many cases this power is materially larger than can be distributed at 2300 volts or even at 4000 volts from one substation. Thus either a higher primary distribution voltage is necessary to make it economically feasible to tap a high voltage transmission line or a double transformation and use of an intermediate voltage circuit. The additional losses and the additional cost usually make the latter uneconomical leaving no alternative but the higher primary distribution voltage. This has led to the introduction of 6600 and 13,200 volts as primary distribution voltages in those cases which cannot be economically developed by the lower primary distribution voltages and so justifies their use.

Industrial power supply due to the large bulk power demanded by a single customer also often requires voltage higher than 2300.

A similar situation arises when changing from a local isolated electric generating plant to a substation of a territorial system. Economically, the substation should be near the center of distribution, that is well within the municipality. But it must be reached by the high voltage transmission line and this immediately raises the question of the transit of the high voltage transmission line through the municipality. The alternative is an additional substation at the city limits with an intermediate voltage leading from there to the substation in the distribution center. This means increased cost and decreased efficiency, that is higher prices of electric service.

It seems to follow herefrom that it is economically undesirable to limit the voltage which can be carried through municipalities on overhead lines; that any voltage, no matter how high, must be permitted provided that the line is designed and built properly and safely for the voltages which it carries. This seems reasonable because a 220,000-volt transmission line, properly designed and built, is no more dangerous than a 2300-volt line; rather less because contact with the latter kills just as quickly as contact with the former but the chances of coming in contact with the latter are materially greater.

The position recommended here to set no voltage limit but permit overhead lines of any voltage provided they are safely designed and constructed, though apparently demanded by industrial progress, has become possible only by the work of the National Bureau of Standards in giving the municipal electrician a definite code and specification of line construction for different voltages.

As regards the question of underground cable versus overhead line: The underground cable is much more expensive than the overhead line, thus increases the cost and thereby more or less indirectly the price of electricity supply. This increase is little where the density of demand is very great as in the center of the city and the better appearance of the street then may justify underground distribution. Often by proper city planning the overhead lines or most of them can be kept away from the main streets and located inconspicuously in alleys, etc., especially in newly developed parts of the city.

To conclude, then, the preceding are general considerations which apply generally but in individual cases modification may be necessary for various reasons.

Protection for Alternating-current Motors

By B. W. Jones

Industrial Control Department, General Electric Company

Good engineering has always dictated that more study and less guesswork should govern the determination of the size of motor for a given drive in order that the motor selected be no larger than necessary. Present economic conditions emphasize this policy. As a consequence, the protection of such a motor is of more importance than formerly. The following article describes protective devices for multi-phase motors of the induction and synchronous types. Editor.

There are three operating conditions against which a multi-phase induction or synchronous motor should be protected.

A. Overload current, which may result from too heavy a load on the motor or from abnormal voltage on the power lines.

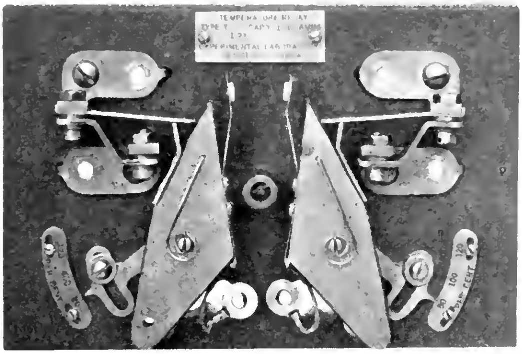


Fig. 1. Temperature Overload Relay. This shows the relay in the tripped position. For normal running the control contacts are closed

B. Single-phase power, which may exist when attempting to start the motor or after the motor has started.

C. Phase reversal, which will cause the motor to rotate in the opposite direction to that intended.

Protection against Condition A

The device which best protects against overloads is a temperature overload relay. Heretofore, overload relays have usually been of the solenoid type, retarded by some form of dashpot or bellows. The current-time curve of these solenoid relays is similar in shape to that of the current-time curve of an alternating-current motor, but generally the relay curve is far below it; i.e., the relay will trip long before it is necessary. Also, this type of relay never can take into account the previous history of the load on the motor. The overload may occur while the motor is cold or it may occur after a long run at rated load, and yet it will require the same time to trip with the same degree of overload under either of these two conditions.

Temperature overload relays, one form of which is shown in Fig. 1, will replace the dash-pot types on control equipments because the characteristics of the temperature relay correspond very closely to the heating characteristics of the motor. Tests have shown that, if overloads varying from 10 to 500 per cent current are put on the motor, the relay will disconnect the motor from the line when the motor temperature reaches approximately its rated value. This will take place if the overload is put on either a hot or a cold motor.

From a mechanical standpoint, the relay is made to meet the requirements that the average industrial plant requires.

From an application standpoint, the relay is made so that the current at which it will trip can be adjusted over a range of 80 to 120 per cent of its rating. The relay will carry continuously the 120 per cent value.

From the standpoint of its thermal characteristics relative to that of the motor, the relay very closely approximates that of the motor.

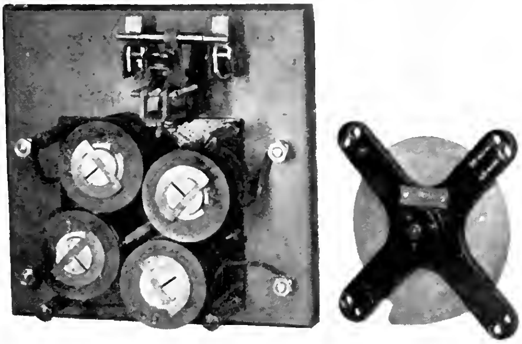


Fig. 2. Open-phase and Phase-reversal Relay with the Steel Yoke and Copper Disc removed to show the construction of the relay

In order that the name "Temperature Overload Relay" may not become meaningless by applying it to a multitude of devices that possess only a small thermal capacity, it is hoped that steps will be taken to outline some requirements which a device of this general character must possess before it can be correctly called a "Temperature Overload Relay."

When these relays are calibrated in the factory they are placed in a room having an ambient temperature of 40 deg. C. and the current values applied until constant conditions exist. In this way the relay is adjusted so that it will trip at its indicated value in an ambient temperature of 40 deg. C., but at a greater or less current value if the relay is in a lower or higher ambient temperature. Thus the relay is fully able under all ambient temperatures to protect the motor against overloads while the motor is running.

Fig. 3. The Open-phase and Phase-reversal and the Temperature Overload Relays are shown mounted in an enclosing case to be used as a unit to give full protection to the motor. The tips of both relays are normally closed and connected in series

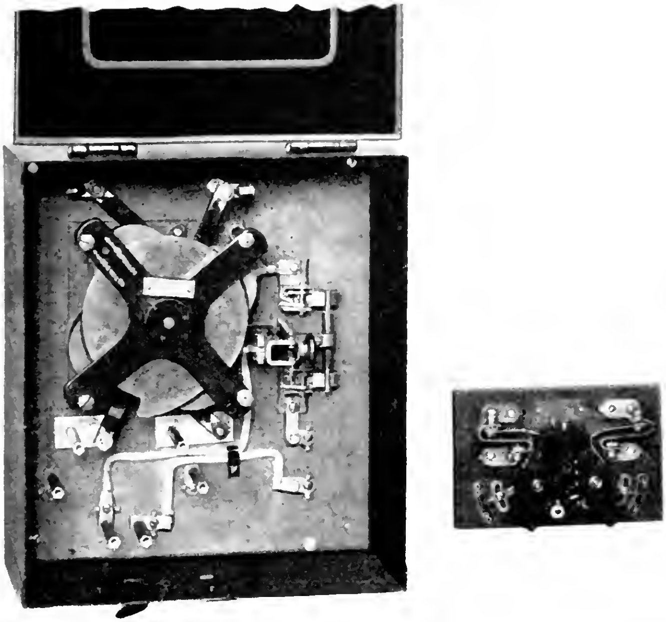


Fig. 4. The Same Panel as illustrated in Fig. 3. The temperature overload relay has been removed to show its method of mounting

Protection against Conditions B and C

There is one condition against which an overload relay can never protect, and that is when single-phase power is applied to a motor when stationary and the current taken by the motor is about its full-load rating or less. Single-phase power can never start the motor and the latter's radiating capacity is greatly reduced due to the armature not rotating and it will therefore reach a dangerous temperature. An open-phase relay will give the required protection.

Single-phase induction relays and also multi-phase induction relays have been built for years. The single-phase relay produces its rotation by a split-phase action in each magnetic pole by means of a pole-shader, and the multi-phase relay produces its rotation by the rotation of a magnetic field from pole to pole similar to any induction motor.

By making a combination of a single-phase and a multi-phase relay and so connecting it that the two rotations oppose each other, we have the basis of an open-phase, phase-failure, and phase-reversal relay. If the multi-phase action predominates, the rotating member comes up against a stop and, even when power is removed, will remain there. If series coils are used and one phase to the motor opens, the three-phase rotation ceases but single-phase power continues and will produce the single-phase rotation of the relay in the opposite direction and cause a latch to be tripped.

The foregoing features may be observed in Fig. 2 which illustrates the relay with its steel yoke and copper disc removed. The relay has four poles and four series coils. Each pole has a pole-shader and is so placed as to produce a torque in the copper disc in a counter-clockwise direction. The steel cross, located as shown in Fig. 3, also acts as a pole-shader to give a torque in the same direction as each shaded pole piece and the two develop quite a respectable torque. With single-phase power these forces cause the disc to rotate counter-clockwise and trip the contact, which is a toggle arrangement.

When multi-phase power is applied, the single-phase torque remains, but there is added a torque produced by the revolving field and this can be in either direction, depending upon the connections. For normal operation these two torques should oppose each other, with the rotating torque predominating. This will bring the copper disc against a stop and produce no further result. Therefore nothing happens when multi-phase power is applied or removed; but, should any phase open, then only single-phase power remains and the relay will immediately trip. The relay requires about 60 per cent of its continuous coil rating to trip. This means that if the motor, when running with an open phase requires less than 60 per cent of its rated current, the relay will not trip, but very few loads will allow the motor to draw less than this amount of current and if so no harm can ever result. It is also very apparent that if phase reversal occurs the relay will trip.

For elevator and hoist service a phase reversal relay is required to protect against a phase reversal condition and against starting the motor if only single-phase power is on the line. Also if a phase fails while the motor is running the relay should not stop the motor because the cage should reach a landing. The relay just described will accomplish these results if shunt instead of series coils are used. However, since this service can be obtained with a smaller and cheaper device this relay is used primarily for the service which it alone can accomplish.

Combined Protection

The panel shown in Figs. 3 and 4 has been designed to include both the temperature overload and open-phase relays. This combination protects multi-phase alternating-current motors against the three conditions mentioned at the beginning of this article.

Equations of the Magnetic Circuit

By Frank M. Gentry

Variable permeabilities in magnetic circuits are troublesome to handle mathematically and we believe that the formula derived by the author should save much time and trouble in calculating magnetic circuits involving variable permeabilities.—Editor.

The solution of problems in magnetic circuits involving variable permeabilities, while not a difficult task, is probably one of the most unpleasant in electrical engineering. The present system of solving such problems is the simple but laborious method of trial and error and even then the answers obtained are not of the highest order of precision. While it is admitted that accuracies beyond about three per cent are not desired because of the uncertainties arising from magnetic leakage, it is also generally admitted that the present method of solution is far from being satisfactory and is tolerated only because there is no other simple way of attacking the situation.

The author has been able to derive some empirical equations capable of giving a direct solution to the simple magnetic circuits and, while they are long and formidable looking, yet it has been found that they are quicker to use and give a more accurate result than ordinarily found by trial and error.

The general equation for the flux in any magnetic path is:

$$\phi = \frac{\frac{4\pi}{10}(NI)}{\frac{l_1}{u_1 A_1} + \frac{l_2}{u_2 A_2} + \ldots\ldots \frac{l_n}{u_n A_n}}$$

where (NI) is the total ampere turns acting, and l_n, u_n and A_n are the length, permeability, and area respectively of the n^{th} region of the magnetic path. Let us obtain first the equation of a simple annular magnetic circuit consisting of a ferromagnetic material of constant area of cross-section and an air gap. In this case then,

$$\phi = \frac{0.4\pi(NI)A}{l_g + \frac{l_s}{u_s}}$$

since the permeability of air is unity and only slight error is introduced by assuming that the area of the air gap is equal to the area of the material.

Froelich has shown that the reluctivity of a ferromagnetic substance is essentially a linear function of the magnetising force. Therefore we may write,

$$\frac{1}{u_s}=a\left(\frac{(NI)_s}{l_s}\right)+b$$

where a and b are constants depending solely upon the nature of the material.

Now it is evident that the magnetomotive force required to maintain a given flux is the sum of the magnetomotive forces required to maintain that flux in the various regions, so that,

$$(NI)=(NI)_g+(NI)_s$$

where $(NI)_g$ is the ampere turns required for the air gap and $(NI)_s$ the number required for the rest of the circuit. Hence,

$$(NI)_s=(NI)-(NI)_g=(NI)-\frac{0.3133\phi l_g}{u_g A}$$

and therefore,

$$(NI)_s=(NI)-\frac{0.3133\,\phi l_g}{A}$$

since $u_g=1$. Combining this with the foregoing equation, we have,

$$\frac{1}{u_s}=\frac{a[(NI)A-.3133\phi l_g]+A\,l_s\,b}{Al_s}$$

and upon further substitution,

$$\phi=\frac{3.193(NI)A}{l_g+l_s\left\{\frac{a[A(NI)-.3133\phi l_g]+A\,l_s\,b}{Al_s}\right\}}$$

which reduces to the quadratic equation,

$$\phi^2[.3133\,al_s\,l_g]-\phi[Al_sl_g+(NI)Aal_s+Abl_s{}^2]-3.193(NI)A^2l_s=0$$

Solving for the ampere turns, we obtain,

$$(NI)=\frac{\phi(.3133\phi l_g a-Al_s b-Al_g)}{\phi aA-3.193\,A^2}$$

and solving for the flux, we find,

$$\phi=\frac{A[l_g+(NI)a+bl_s]-\sqrt{[A(l_g+(NI)a+bl_s)]^2-4A^2(NI)\,al_g}}{0.6266\,a\,l_g}$$

Table I gives the values of the constants a and b in the above equations for various materials as determined from the mean of several measurements.

TABLE I

Material	Constants	
	a	b
Cast iron.	.0000150	.00220
Cast steel (soft) . . .	.0000262	.00051
Annealed steel (sheet).	.0000270	.00023
Cobalt (soft).	.0000435	.00320
Nickel (99 per cent). . .	.0000521	.00164

Placing $l_g=0$ in the first formula, we obtain the equations for a simple magnetic circuit without an air gap:

$$(NI)=\frac{-\phi l_s b}{\phi a-3.193A}\quad\text{and}\quad\phi=\frac{3.193A(NI)}{(NI)a+l_s b}$$

By generalizing the derivation, it has been found that for a simple magnetic circuit made up of a single substance but with two regions of different length and area,

$$(NI)=\frac{0.3133\phi^2a(l_1+l_2)-\phi b(l_1A_2+l_2A_1)}{\phi a(A_1+A_2)-3.193A_1A_2}$$

and for the case of two regions of different ferromagnetic substances of equal areas,

$$(NI)=\frac{0.3133\,\phi^2(a_1l_2+a_2l_1)-\phi A(l_1b_1+l_2b_2)}{\phi A(a_1+a_2)-3.193A^2}$$

and finally for the general case of two regions with different permeabilities, lengths and areas,

$$(NI)=\frac{0.3133\,\phi^2(a_1l_2+a_2l_1)-\phi(l_1A_2b_1+l_2A_1b_2)}{\phi(a_1A_2+a_2A_1)-3.193A_1A_2}$$

These equations are valid only for magnetising forces between ten and two hundred ampere turns per inch because the assumption of a linear reluctivity holds only for that interval. Luckily, however, the values most common in practice fall within these limits. Unfortunately no terms in the above formulæ can be neglected because they are usually of the same order. English units are to be used.

As an example of the application of these formulæ to problems in the magnetic circuit, if the first equation be applied to problem 31 on page 195 of "Hudson's Engineering Electricity," it will be found that the answer works out correctly to less than one and a quarter per cent.

Gauges

By G. C. Reilley

Gauge and Tool Department, General Electric Company, Schenectady, N. Y.

It is almost superfluous to state how important accurate gauges are to modern manufacturing operations. We are fortunate in having an article from "a man in the shop" who has built up a gauge system that works so satisfactorily. Mr. Reilley tells his story in his own way and we believe his contribution will be of great value to others responsible for similar work. After some historical notes he tells about the types of gauges used and the methods of using them.—Editor.

All industrial concerns are endeavoring to obtain two results that are rather difficult to accomplish; i.e., cheaper production and greater accuracy in the manufactured units that go to make up the finished article. This not only requires modern machine tools and small tool equipment, but a complete gauge system. As a matter of fact, gauges are the vital part of modern accurate and satisfactory manufacturing methods, the essential results being the ability, not only to work to extremely close limits where necessary, but to be able to duplicate absolutely the various parts at different intervals, sometimes after the lapse of years. In order to accomplish this, it is necessary that a comprehensive gauge system be established, the gauges must be of the utmost refinement, and a method followed to insure the gauges being always in proper condition.

As the mechanical arts advanced and industries were developed for producing machinery for various purposes, naturally the tools used in their production advanced accordingly; not only cutting tools, but measuring tools such as micrometers, verniers, etc. The making of this machinery created complexities that had to be overcome, especially the duplication of parts.

The difficulty of the different interests agreeing on a standard is illustrated by the different standards of screw threads. The Whitworth Standard was accepted in England as long ago as 1841. This, however, not being metric is not in use on the continent of Europe. The Seller's Standard was introduced in the United States in 1864 and is known as the U. S. Standard, above ¼ inch. In all countries there are eight threads that have been standardized, out of sixty systematized.

The weights and measures in common use in this country at the time of the Revolution were of English origin, and were in use in England at that time. The principal units were the yard, the avoirdupois pound, the gallon and the bushel. In 1790, a committee of the House of Representatives were requested to prepare a bill for a proper plan for establishing uniformity in weights and measures, the English standards never having been adopted by the government, but they were being used on account of our not having a standard of our own.

While Congress had been considering the matter, most of the states had independently of each other secured and adopted standards. Standards of the same denominations differed widely, thus causing confusion in the commerce between adjacent states.

In 1828 an act of Congress made the troy pound the standard for coinage. This is the standard from which the avoirdupois pound in common use is derived. The Treasury Department finally adopted a standard, I think in 1830, making the yard 36 inches, the avoirdupois pound 7000 grains, the gallon 231 cubic inches, and the bushel 2150 cubic inches approximately. The 36 inches adopted for the yard was the distance between the 27th and 63rd inches of an 82-inch brass bar prepared for the coast survey in London. This bar had been brought to America in 1813, and the 36-inch space referred to was supposed to be identical with the English standard at 62 deg. F.

In 1866 Congress passed an act legalizing the metric system of weights and measures in the United States. This, however, has never been put into effect up to the present time.

How the yard measure originated in England in the first place, I am unable to say. The French, however, had a definite reason for the metric system. For example, the meter, which is the measurement of length, equals one ten-millionth part of a meridian quadrant of the earth. This in English measure equals 39.37 inches.

One tenth of a meter in cube form filled with water equals one liter, which is equivalent to approximately one of our quarts.

While one tenth meter, or decimeter, in cube form equals one liter in capacity, it also equals one kilogram in weight, which is approximately 2.2 pounds. So the meter has a direct relation to length, capacity, and weight.

Having these standards, both English and metric to start with, it is then a question of making duplicates and subdivisions thereof to work from in manufacturing and commercial pursuits. The yard is subdivided into feet, inches and fractions thereof. Therefore, in order to have interchangeability and duplication of all parts made to the same nominal dimension, it is necessary to have tools and gauges of proven accuracy for use in fabricating the manufactured parts.

In the early stages of machine building, where only a few parts of one kind were made at a time, and each part fitted to the machine or instrument for which it was intended, and made by the same firm, this was not so important. Under the present-day conditions, however, where enormous quantities of different articles are constructed and component parts made at different places, it is absolutely necessary to have ways and means of being sure that all parts are duplicates, and therefore interchangeable.

To accomplish this, gauges recognized for their accuracy by the United States Bureau of Standards, and also the different foreign countries (where the firms do an international business) must be used as master or reference gauges, duplicates of these gauges to be used as working and checking gauges. This requires a department where the master gauges are kept under the proper temperature. For this purpose we have built a room 21 by 21 feet in the middle of a concrete building with the walls of cement block 18 inches thick so that there is absolutely no opportunity for outside atmospheric conditions to affect the temperature in this room.

All of the master gauges of the different types are kept in this room. Figs. 1 and 2

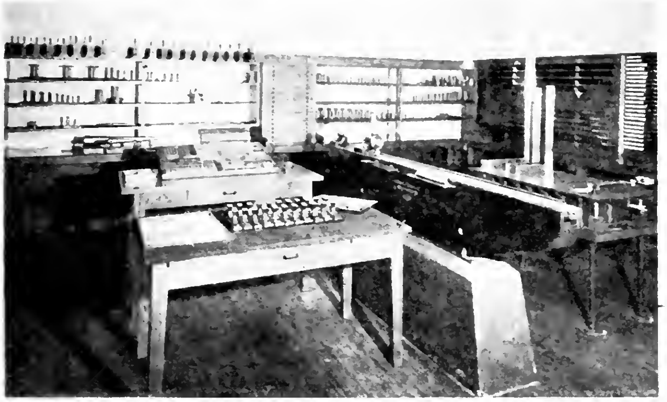


Fig. 1. Constant Temperature Room of Standards

Fig. 2. Another View of Constant Temperature Room of Standards

In addition we have a room 20 by 25 feet where are maintained the reference gauges that are used for checking the working gauges. Fig. 3.

The end measuring standards used by the Schenectady Works of the General Electric Company are the Johansson gauges. The set we have consists of 117 pieces, and has a range from 0.02005 inch to 20 inches. This set will give hundreds of thousands of combinations. See Fig. 4.

These gauges are rectangular pieces of Swedish tool steel, hardened, ground and lapped. They solve four universally recognized mechanical and metallurgical problems; i.e., flat surfaces, parallel surfaces, and effective heat treatment and seasoning. To make flat surfaces in steel is difficult. Parallel surfaces in steel are also recognized as a problem in mechanics. Accuracy in producing flat surfaces that are parallel to each other adds to the problem of having these flat and parallel surfaces a distance apart equal to the size which they represent. These blocks are heat treated and seasoned so that the molecules of the steel are claimed to be at rest. Because of this fact, the usual warping and growing of the metal is checked, and when motion is produced by temperature changes, the steel not only expands and contracts uniformly, but returns to its normal size.

By using these blocks in combination with a measuring machine with a capacity up to 80 inches we are able to produce gauges of almost any length within extremely close limits. When Mr. Johansson first described his gauges and said they were within one hundred thousandths of being correct, most people doubted this statement, and those that did not still said there was no occasion for such refinement, while as a matter of fact, it is absolutely necessary that they are within one hundred thousandths of being correct. As an example, when we are required to make a gauge of considerable length, it is sometimes necessary to build up a number of the Johansson blocks in order to obtain the size required. If this occasions the use of thirty of the Johansson blocks, for example, and there was a variation of one hundred thousandths in each block, this would make an accumulated error of three ten thousandths, which would be absolutely out of the question, as at the present time in our Commutator Department there is an allowance of only five ten thousandths (0.0005) inch between the diameter of the bore of the commutator and the shaft. There is no tolerance to this dimension, as it is necessary that the shaft be five ten thousandths (0.0005) inch larger than the bore in order to obtain the proper pressure fit. Therefore, if there was an error of three ten thousandths in the gauges used for this work, the proper pressure would not be obtained, and consequently the work would not pass inspection.

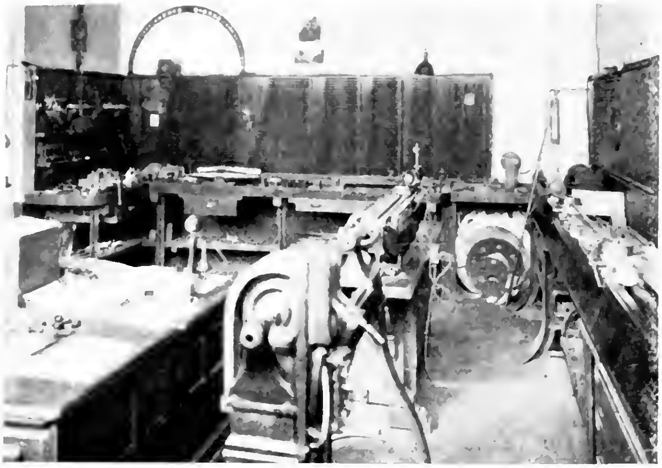


Fig. 3. Gauge Inspecting Room

It is very difficult to conceive what one hundred thousandth really means. Some statistician has figured that if an inch was divided into one hundred thousand parts in the form of playing cards, it would take a person over seven hours to deal these cards at the ordinary rate, that is about four a second.

In addition to the Johansson gauges, we have a Van Keuren Light Wave Measuring Outfit. This equipment consists of a set of optical glass flats and a source of monochromatic light.

An "Optical Flat" differs from a lens in that it has no magnifying power; but its utility consists solely in that it is a very accurate transparent flat test surface. The "Working Flats," 2 inches in diameter by ⅝ inch in thickness, each have one surface accurately flat, *within five millionths* of an inch. Only one of these is required for flatness tests, and the two suffice for length measurements or comparisons.

One "Master Flat," 2¾ inches in diameter by ⅞ inch in thickness with one surface accurately flat, *within 2½ millionths* of an inch serves to complete the set of optical flats. Thus the two working flats and the master can be proven absolutely by testing them against each other, employing the familiar principle that three surfaces fitting together in all combinations establish or originate flat surfaces. The master flat in addition to its value for reference purposes can be used on larger work than the working flats.

The monochromatic light set is a most practical outfit specially designed for every day use. It consists of a conveniently constructed, nicely finished oak box, provided with a tungsten filament lamp and a special selenium diffusing glass. This selenium diffusing glass cuts out all of the violet, blue,

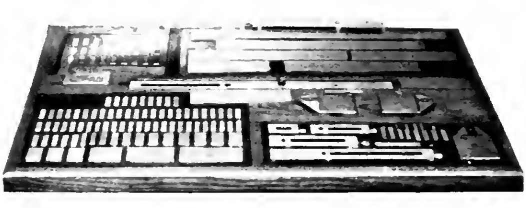


Fig. 4. Johansson Gauges in Constant Temperature Room of Standards

green, yellow and orange waves; and transmits only a very definite red wave of known length, resulting in an equivalent measuring unit of eight dark interference bands to the ten thousandths of an inch or 12.5 millionths per band. It can be attached immediately to an alternating or direct current lamp socket.

Interference bands, or alternate light and dark spaces, can be seen in monochromatic light when an optical flat is placed upon a nearly flat lapped or polished reflecting surface. The illustration, see Fig. 5, shows the character of these interference bands which tell the whole story.

An examination of the bands occurring due to the interference of the light reflected from the upper surface of the two gauge blocks which are wrung on a lower glass flat, with the light reflected from the contacting surface of the upper flat reveals the following facts:

1. The pronounced light space near the observer on each gauge indicates the point of contact.

2. The upper flat is sloping upward toward the rear at the rate of 12.5 millionths of an inch per dark band. At the rear of the right hand gauge there is, therefore, an air space of 5 times 12.5 millionths or 62.5 millionths.

3. The bands on each gauge curve about 2/10 of the distance between them, and the center of curvature is on the same side of the bands as the point of contact, thus indicating a convex surface with edges lower than the center by 0.2 times 12.5 millionths or 2.5 millionths.

4. The bands on the left hand gauge occur about ½ band lower down on the wedge than those on the right hand gauge, indicating that the left hand gauge is shorter by ½ unit or a little more than 6 millionths of an inch.

6. The bands on both gauges although slightly curved are practically parallel, indicating that the upper surfaces of the two gauges, as they are wrung on the lower flat, are parallel within one or two millionths of an inch.

With our present system all manufacturing departments are furnished with necessary gauges pertaining to their class of work. This insures accurate and absolute interchangeability. These gauges are numbered serially and assigned to the different departmental gauge rooms, where they are given to the workmen. All gauges in use in the factory during the week are returned to the main gauge room at least once a week for recalibration, in other words, no gauge is in use longer than one week without being checked.

The accuracy of these gauges is of extreme importance, as some of the work is of the greatest refinement. A case in point is the making of gears for the turbine gear reduction sets for the destroyers for the United States Government. Some of these gears were as large as 72 inches in diameter, and the gear cutters used for cutting the teeth were made in hob form of the greatest accuracy. These hobs were made of high speed steel and ground all over. On account of the size of these gears, and the accuracy desired, a "snap gauge" or "outside gauge" could not be used for finishing, and we therefore decided to use a steel tape. This tape was 3/8 inch wide by 0.008 inch thick, and was made to the exact length represented by the circumference of the gear. As the pitch line of the gear was determined from the outside diameter, it was necessary that this be of the greatest possible accuracy, due to the fact that the engineers would only allow an accumulative error of three thousandths in the total periphery of the gear after the teeth had been cut. As the 72-inch gear had 288 teeth, this was only a permissible error of approximately one hundred thousandth of an inch between the pitch of the teeth.

Fig. 5. **Interference Bands on Two Flat Gauge Blocks That Are Being Compared for Length and Parallelism**

The length of the tape is obtained in a machine designed specially for the purpose.

First. One end of the steel tape is inserted in the slot in clamping block and clamped. See Fig. 6. The tape is then passed around the stationary head and around the movable head back to a slot in clamping block and butted to its opposite end. A tension of four pounds is used to straighten out the tape. A pin gauge of the desired length is inserted between the two heads and should check with the desired length of tape when calculated according to the following formula: See Figs. 7, 8 and 9.

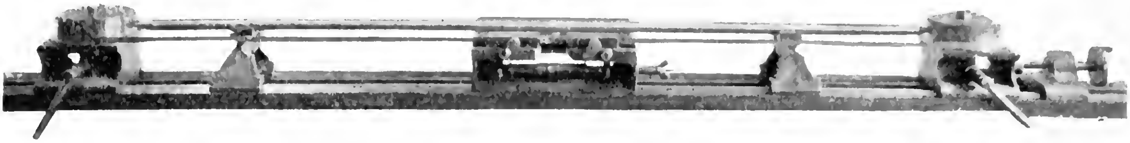


Fig. 6. Tape Measuring Machine

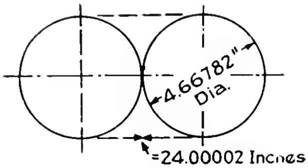


Fig. 7. Position Without Tape

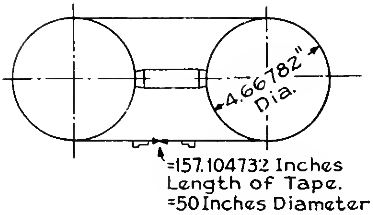


Fig. 8. Developed Length of Tape

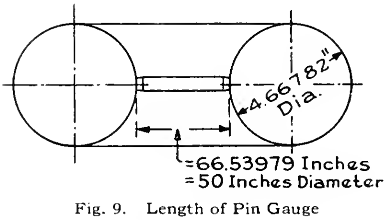


Fig. 9. Length of Pin Gauge

In Fig. 7, $\frac{1}{2}$ dia.$\times 2 \times \pi +$(radius$\times 4$) $= 24.00002$ inches.

In Fig. 8, 24.00002 inches$+0.025132+$(pin gauge$\times 2$)$=$developed length of tape.

In Fig. 9, length of pin gauge

$$= \text{developed length of tape} - \frac{24.025152}{2}$$

In each instance the thickness of the tape (0.008 inch) must be considered part of the diameter of the fit. This thickness, namely, 0.008 inch, equals 0.025132 inch in circumference, and for the sake of convenience after the circumference of the diameter has been obtained this is added; for example, the actual circumference of 50 inches is 157.0796, and with the thickness of the tape added it makes the actual length of the tape 157.104732 inches.

As a great number of our generators are direct driven by engines or waterwheels made by outside manufacturers both in the United States and abroad, it is necessary to send gauges to these different manufacturers for finishing the shafts upon which our generators are mounted, and as the generator spider must go on these shafts at a definite pressure the gauges naturally must be absolutely correct. In the past year we shipped hundreds of gauges to outside builders, a large percentage going to England, France and Switzerland on contracts made by the International General Electric Company.

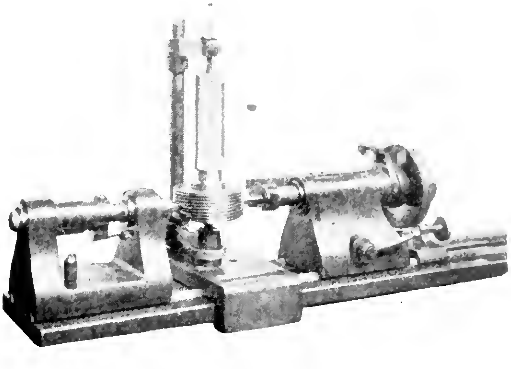


Fig. 10. Machine for Measuring Thread Gauges
Three-wire System

When it is realized that every piece of apparatus made by the General Electric Company can be duplicated at any time, and supply parts furnished or break-downs replaced with full assurance that when the parts are received by the customer they will fit, the necessity of a comprehensive gauge system can be appreciated.

The gauges which are sent abroad are used on apparatus to be installed in different parts of the world; i.e., in Australia, South Africa, India, etc. I remember a case several years ago, where a Swiss manufacturer made the waterwheels for our generators, of which there were ten in number, all duplicates, of 12,500 h.p. capacity. These were for a large mining concern in South Africa. These were waterwheel driven generators, and the shaft upon which our rotors were mounted was part of the waterwheel.

We sent the gauges and instructions to the Swiss manufacturers for the making of these shafts and owing to the size there were three different fits in the armature spiders. The waterwheels were sent to South Africa from Switzerland, and our generators from Schenectady. Therefore, the parts to be assembled did not come together until they reached their destination. The respective members fitted perfectly, and the installation proved to be entirely successful, proving quite conclusively that the gauges exchanged fulfilled all requirements.

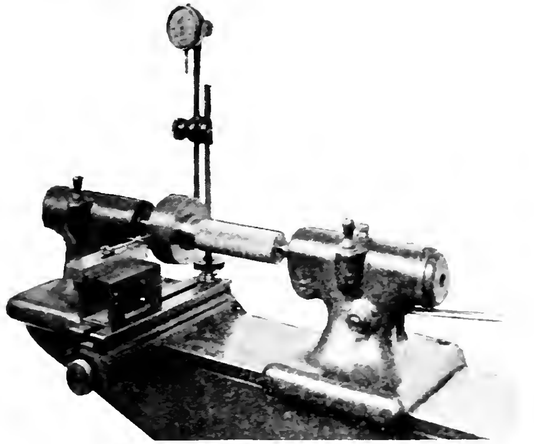


Fig. 11. Machine for Checking the Lead of Screw Threads

Our method of determining the accuracy of thread gauges is by what is known as the "Three Wire Method of Measuring Threads." The angle diameter determines the depth of the thread. It is therefore vital to have this angle diameter accurately determined.

The three wire method of measuring threads is the best. Two wires are placed in the threads on one side, close enough together so that they will be covered by the anvil on measuring machine, while the third wire is placed on the opposite side midway between the two wires. The machine measures the distance between the outside diameters of the wires and gives accurate results. Definite diameters of wires are used for the various pitches. These wires are accurate within 0.00002 inch. See Fig. 10

In addition to measuring the outside and angle diameters of all thread gauges, we also determine the lead or pitch, with an indicator that registers within 0.0001 inch. See Fig. 11.

We have complete sets of thread gauges for checking the working gauges (Fig. 12), and also

Fig. 12. Cabinet of Reference Thread Gauges

master sets of gauges to be sure our checking gauges are always correct.

The number of new gauges made for use in the factory during the year amounts to approximately 3300. In addition to this we forward to outside waterwheel and engine builders about 1200 gauges yearly. We inspect, on an average, 400 gauges each working day.

High-voltage Thermionic Rectifiers

By A. Schmidt, Jr.

Radio Engineering Department, General Electric Company

The development of three element vacuum tubes or pliotrons for use as generators of radio-frequency power has been accompanied by the requirement for a power supply of high-voltage direct current, which is applied between the plate and filament of the three-element tube. At lower powers the high-voltage direct current is obtained from a direct-current generator with a rotating armature. At higher voltages than are obtainable from such machines, however, it has been necessary to develop other means for obtaining this supply. The kenotron rectifier has been developed primarily for this purpose in connection with radio telephone and telegraph transmitters, although it is applicable to other uses where a high-voltage direct-current power supply is required.—Editor.

Nearly two decades ago the vacuum tube was first observed to possess the property of a converter of direct-current to alternating-current power. This discovery was made with a gas-content receiving tube operating with 20 to 40 volts on the plate and probably delivering less than a milli-watt of alternating-current power. Development of this new converter progressed; and several years ago a high-vacuum tube was built to deliver 250 watts of alternating-current power, receiving direct current from a 2,000-volt generator.

Further increase in power output is made possible by increasing the size of the tube or by operating it at a higher voltage. The latter alternative is preferable as it is in the direction of higher efficiency. Accordingly, a tube was developed to convert one kilowatt of alternating-current power from a direct-current source of 10,000 volts. Subsequent development has increased the capacity a hundred-fold with an accompanying increase in operating voltage to 15,000. The development in high-voltage direct-current generators has followed the development of the vacuum tube, but has been less intensive.

Paralleling the development of the vacuum tube as a direct-current/alternating-current power converter is the development of the vacuum tube as a rectifier or converter of alternating-current power to direct-current power. For every pliotron, or direct-current/alternating-current converter, there is a corresponding kenotron, or alternating-current/direct-current rectifier, differing in construction only by the removal of the grid or control element. The maximum operating voltage of any particular type of pliotron is determined chiefly by the construction of the tube. Inherent features of operation of the kenotron and pliotron indicate that the kenotron may be operated at a higher voltage than the corresponding pliotron, so that any demand for a new maximum operating voltage, created by development of the new pliotron, may be met by the use of the corresponding kenotron.

TYPES OF RECTIFIERS

The usual form of a high-voltage rectifier consists of a suitable step-up transformer and one or more kenotrons. The rectifier may be single, two, three, or six-phase depending upon the power supply, and in each case the kenotrons may be connected to rectify one or both halves of the alternating-current voltage wave.

In general, full-wave rectifiers are preferable to half-wave rectifiers for the following reasons:

(1) The full-wave rectifier delivers a smoother voltage wave.

(2) The half-wave rectifier operates the step-up transformer with a direct-current component of flux in the core, with corresponding high iron losses.

(3) The step-up transformer in a half-wave rectifier draws an unsymmetrical current from the line, with large even harmonic components. The accompanying poor regulation is usually objectionable.

(4) In the case of a polyphase rectifier, the resultant even harmonic voltages set up in the line have a phase rotation opposite to that of the fundamental. This is highly objectionable in the case of rotating machinery operating on the line.

The chief advantage of half-wave rectification lies in the smaller number of kenotrons required.

Single-phase Half-wave Rectifier

Fig. 1A shows diagrammatically a single-phase half-wave rectifier connection, and Fig. 1B the resultant voltage wave with its alternating-current and direct-current components. A step-down transformer is used to heat the filament of the kenotron. When the negative terminal of the rectifier is grounded, as is usually the case in pliotron circuits, the low-voltage winding of this transformer must be insulated for the full voltage of the step-up transformer to ground. The resistance *R* is for the purpose of regulating the filament temperature. It will be noted that the positive terminal is located at the mid point of the filament winding, instead of on one of the filament terminals, because this connection divides the space-charge current in the kenotron equally between the two legs of the filament. This insures equal temperatures in the two legs, thus increasing the life of the filament.

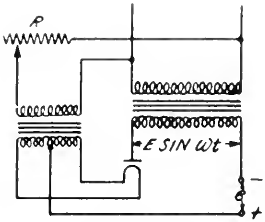


Fig 1 A

$e=E(.318+.5\ SIN\ \omega t-.212\ COS\ 2\omega t-.0423\ COS\ 4\ \omega t)$

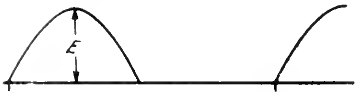


Fig. 1 B

Figs. 1A and 1B. Diagram of Connections and Curves for Single-phase Half-wave Rectifier

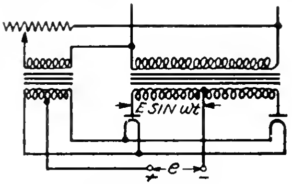


Fig. 2 A

$e=E(.637-.424\ COS\ 2\omega t-.0848\ COS\ 4\omega t-.0364\ COS\ 6\omega t)$

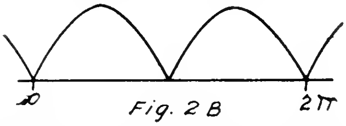


Fig. 2 B

Figs. 2A and 2B. Diagram of Connections and Curves for Single-phase Full-wave Rectifier

Single-phase Full-wave Rectifier

Fig. 2A shows a single-phase full-wave rectifier connection employing two kenotrons. Fig. 2B shows the resultant voltage wave with its direct-current and alternating-current components. It will be noted that the [illegible] of the direct-current component of the [illegible] wave to the total alternating-current voltage of the transformer is the same for the full-wave and the half-wave single-phase rectifier.

Three-phase Half-wave Rectifier

Fig. 3A shows a three-phase half-wave rectifier connection. The transformer and rectifier voltage waves are shown in Fig. 3B, the dotted lines representing the transformer voltage waves. The current wave follows the rectified voltage wave, assuming negligible resistance and reactance in the rectifier. The reason for this lies in the valve action of the kenotron so that, at any instant, only the kenotron with the highest positive potential on its plate will pass current. Thus, each tube passes current for one third of a cycle. The primary current in the transformer is unsymmetrical, and in the limiting case of high reactance in the load, assumes the square wave shape shown in Fig. 3C. This wave if analyzed is found to have a second harmonic component with a magnitude of 50 per cent of the fundamental and a fourth

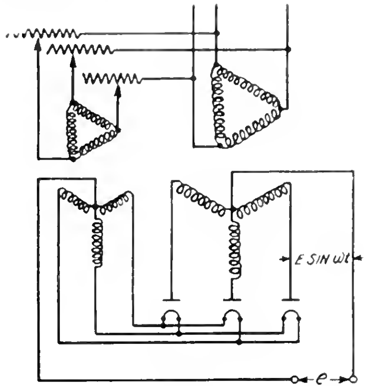


Fig 3A

$e=E(.827-.207\ COS\ 3\omega t-.0472\ COS\ 6\omega t-.0207\ COS\ 9\omega t)$

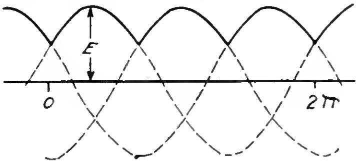


Fig. 3 B

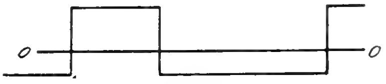
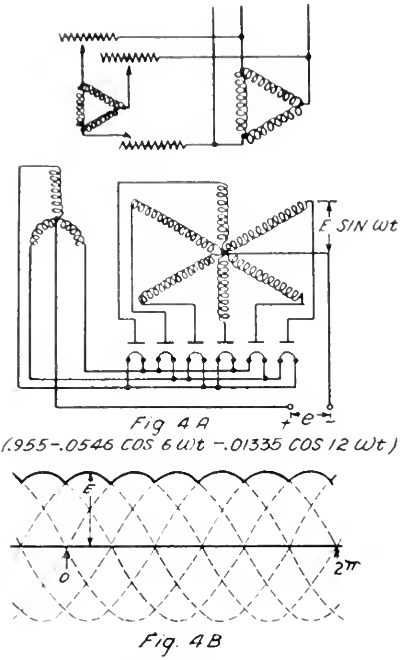
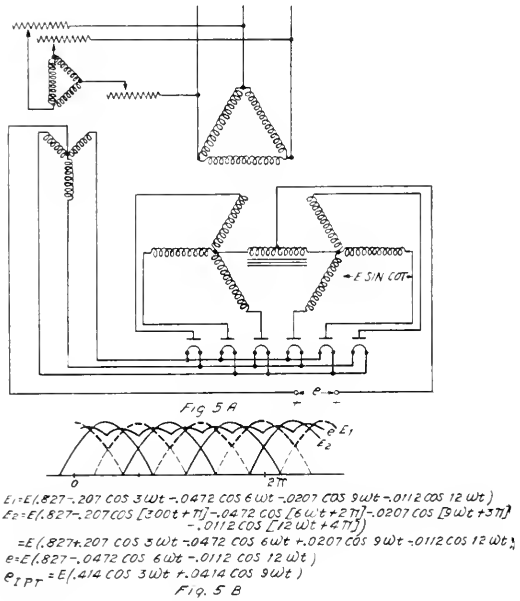


Fig 3 C

Figs. 3A, 3B and 3C. Diagram of Connections and Curves for Three-phase Half-wave Rectifier



Figs. 4A and 4B. Diagram of Connections and Curves for Three-phase Full-wave Rectifier



Figs. 5A and 5B. Diagram of Connections and Curves for Three-phase Double-Y Rectifier

harmonic with a magnitude of 25 per cent of the fundamental, besides other higher even harmonics of lesser magnitude. As previously indicated, these harmonics are objectional especially if the rectifier is a large unit, drawing considerable harmonic power from the line

It will be noted that Fig. 3A shows the filaments being heated from a three-phase circuit. This is done so that the filament and space-charge currents will add up equally in all the kenotrons and produce equal filament temperatures. If all the filaments are lighted from one phase, the phase angle between filament and space-charge current will differ by 120 deg. in successive tubes, and the sums will not be equal. The resultant unequal filament temperatures shorten the mean filament life. Another method of securing equal filament temperature is to heat the filaments from a single-phase source not synchronous with the three-phase source.

Three-phase Full-wave Rectifier

Fig. 4A shows a three-phase full-wave rectifier and Fig. 4B the resultant transformer and rectifier voltage waves. The step-up transformer for such a rectifier is wound with mid taps on each of the three phases and these are joined together to form the negative terminal of the rectifier. It will be noted that the currents drawn from the two sections of each secondary winding are equal and opposite in sign, hence the primary current is symmetrical and contains no even harmonics.

Since each tube passes current only when the voltage on its plate has a higher positive value than on any other plate, it follows that in the three-phase half-wave rectifier each tube passes current for one-third of the cycle, while in the three-phase full-wave rectifier each tube passes current for only one-sixth of a cycle. Thus it follows that three-phase half-wave rectification is preferable to full-wave rectification in that it utilizes the filament emission to a much greater extent. On the other hand, full-wave rectification is more desirable on account of its better regulation,

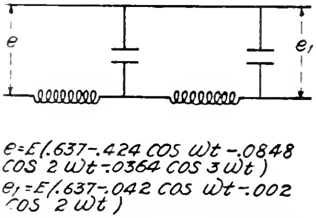


Fig. 6. Diagram of Filter for Suppressing Harmonic Components in the Direct-current Rectified Wave

absence of even harmonics in the line, and smaller harmonic components in the rectified voltage wave.

Three-phase Double-Y Rectifier

The advantages of both full-wave and half-wave polyphase rectifiers may be realized by connecting the high-tension windings of the transformer to form two Y's, 180 deg. out of phase, as shown in Fig. 5A. Each Y, with its kenotrons, is a half-wave rectifier delivering voltage waves, E_1 and E_2 as shown in Fig. 5B, with the odd multiples of the triple-harmonic component in the two Y's 180 deg. out of phase and the even components in phase. If we connect the neutral points of the two Y's through a large reactance, and draw current from the rectifier through the mid-point of the reactance, the odd multiples of the triple-harmonic component will not appear in the rectified voltage wave, since their value is zero at this point but the even-harmonic components will appear. The voltage across the reactor, or interphase transformer, is the sum of the absolute values of the odd multiples of triple-harmonic frequency voltage due to each Y. The current due to this voltage is the interphase transformer magnetizing current, and circulates through the kenotrons and transformer windings without appearing in the load.

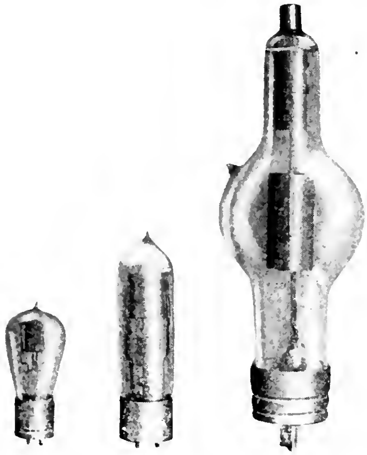


Fig. 7. Left to right—20-watt 400-volt Kenotron, 150-watt 1000-volt Kenotron, and 2.5-kw., 15,000-volt Kenotron

The current waves drawn through each kenotron are nearly square, lasting for one-third of the cycle. Since there are two high-tension windings per phase passing current in opposite directions, the primary-current wave is symmetrical and contains no even harmonics. The direct-current component of current delivered by each of the two Y's is one-half of the total direct-current current, so that each tube is required to pass only one-half the maximum value of current required per tube in the ordinary three-phase full-wave rectifier This means that the filament temperature may be lower since less emission is required, and the filament life is accordingly prolonged.

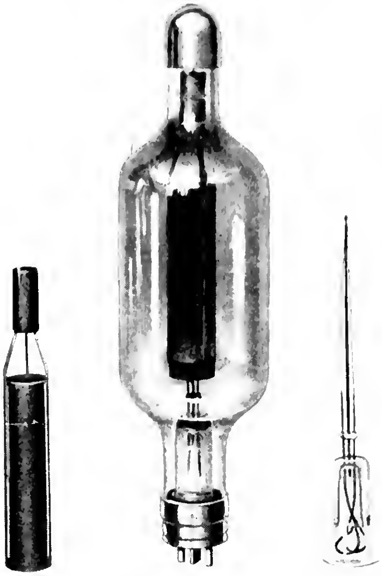


Fig. 8. 12.5-kw., 15,000-volt Kenotron, and its parts at left and right

Fig. 9. Water cooled Kenotron; 40 kw., 15,000 volts

High-power Rectifiers

The presence of harmonic components in the direct-current rectified wave is frequently undesirable and means are taken to suppress them by using filters such as shown for example in Fig. 6, where e represents the voltage delivered by the rectifier and e_1 is the load voltage due to the filter.

IN MEMORIAM

William Jared Clark, Advisory Manager of the Railway Department of the General Electric Company, and for many years an authority in the electric railway field, died at his home in New York City on December 12, 1922, after a long illness. He was 68 years old and had been connected with the General Electric Company and its predecessor, the Thomson-Houston Company, for 34 years. He is survived by his wife and two sons, Harold and William Clark.

He was born in Derby, Conn., on July 20, 1854, of an old Connecticut family. He left school at the age of 14 years, after two years study at the local high school, and became a clerk in the local post office. In 1879 he was temporarily appointed postmaster of Birmingham, Conn., and thus became familiar with political conditions to such an extent that he was permanently appointed to the position of postmaster contrary to the recommendations of the Republican political machine then in control. Acting upon the advice of the late William Wallace, pioneer of the arc lighting and motor production, and attracted by the possibilities presented by electric traction, Mr. Clark entered the electric field and participated in the commercial expansion of almost every phase of the Thomson-Houston and the General Electric Companies' business throughout the world. In the spring of 1888 he induced the Thomson-Houston Company to purchase the Vandepoele Electric Railway patents, which in his opinion were essential to the fullest development of the industry. He recognized at an early date the value of certain fundamental electrical inventions and was instrumental in bringing these inventions under the control of his Company.


WILLIAM JARED CLARK

Mr. Clark was a pioneer in the commercial development of electric railways, beginning his connection with this industry with a project for the first electric railway in the world intended for freight traffic. The legislative charter for this line, which was constructed between Derby, his native town, and Ansonia, Conn., was obtained largely through Mr. Clark's efforts.

Shortly after this Mr. Clark, in March, 1888, became Railway Sales Agent under General (then Captain) Eugene Griffin, who then was General Manager of the Railway Department of the Thomson-Houston Company. In 1893 he was Manager of the Cincinnati Office for a short time, and took an active interest in the earlier electric railway projects of the middle west. In 1894 he came to Schenectady as General Manager of the Railway Department of the General Electric Company. In this position Mr. Clark played an important part in the commercial exploitation of Sprague's Electric Railway Motor Suspension; Vandepoele's Carbon Commutator Brush; the Pivoted Under-running Trolley; Potter's Series Parallel Control; Sprague's Multiple Unit Train Control; Curtis Steam Turbine and other inventions. In 1896, he made a valuation of the electric railway and lighting property in Milwaukee. This is said to have been the first extended "Physical Valuation" of a large public utility and the general plan adopted by Mr. Clark has since been frequently followed by other students.

Mr. Clark's next move was the managership of the Foreign Department of the General Electric Company, taking up the duties of this office in 1899.

The universal esteem which was felt toward Mr. Clark by all of the officers of the Company could not be more clearly shown than by quoting the following letter sent out under date of January 5, 1899, by General Griffin to the entire General Electric organization.

In view of the growing volume and importance of our export business, Mr. W. J. Clark has been appointed General Manager of the Foreign Department of the General Electric Company, having been transferred thereto from his present position as General Manager of the Railway Department.

Mr. Clark's connection with this Company dates back to 1888, when he was the first salesman in the Railway Department of the Thomson-Houston Company. Even before that time he was actively interested in electric railway work. His services have been continuous with the Thomson-Houston Company, from 1888 until that Company was merged into the General Electric Company, and with the latter Company up to the present time. Since 1894 he has been General Manager of this important department.

Mr. Clark has been connected longer with electric traction work than any man in the Commercial Department of this or any other electric company in the United States. His indefatigable energy, extensive and detailed knowledge of the business, his wide-spread acquaintance with street railway men throughout the United States, and in fact, throughout the world, have gained for him hosts of strong friends, whose good wishes he will take with him from the position he has so long filled with such distinguished ability, energy, tact and success, to his new field of work, which includes a very large and growing railway business extending over the entire globe.

I know that all the employees of this Company will join with its officers in wishing him, what we all know he will have, every success in his administration of our Foreign business.

Yours very truly,
(Signed) Eugene Griffin,
First Vice-President.

The activities of the General Electric Company at that time were just beginning to take large proportions and Mr. Clark spent a considerable part of his time in Europe and other foreign countries in preparation of facilities for handling foreign business. He was instrumental in reorganizing the British Thomson-Houston Company at the time control was assumed by General Electric interests, and also established the London Office of the General Electric Company.

Mr. Clark's acquaintances among the prominent members of the electrical industry extended to all the capitols of Europe where he was considered an authority on electric railways and electrical manufacturing conditions. In 1908 he was retained as an expert on Cuban affairs for the War Department and made an extensive study of commercial conditions in the Island of Cuba. Acting upon his recommendations, the electrical facilities were placed on a sound basis and have since been maintained in a satisfactory condition. In connection with his Cuban studies, Mr. Clark wrote a book entitled "Commercial Cuba" giving an exhaustive analysis of the situation, which is recognized as an authority on this subject.

While still occupying the position as Manager of the Foreign Department, Mr Clark was appointed, on December 26, 1905, Manager of the Traction Department of the General Electric Company, which had just been organized to negotiate for heavy steam road electrification work. In this field Mr Clark made many confidential studies, acting directly under the instructions of Mr. C. A Coffin, then President of the Company. At this time and since then his headquarters have been at the New York Office of the General Electric Company.

During practically all of his connection with this industry he has been in close touch with the Federal Government dating back from the time when he was engaged with the Secret Service Branch of the Post Office Department including activities during the Spanish and European wars. The statistics prepared by Mr. Clark covering the corporate relations and interconnections of German Manufacturing Companies and their allies and subsidiaries in the United States were enormously useful to the Federal Government during the European War. In 1922 the Traction Department was consolidated with the Railway Department at Schenectady and Mr. Clark was given the title of Advisory Manager, which he held at his death.

Mr. Clark throughout his life retained his interest and activity in the Republican political organization, being a member of the National Committee campaigns of 1880, 1884, 1896, 1904. In 1906 and 1907 he was chairman of the Ways and Means Committee of the National Civic Federation in which connection he financed the extensive investigations then being conducted of municipal ownership in this country and in Europe. He was a member of a large number of National Electrical and Railway Engineering Societies including the following:

American Institute of Electrical Engineers
National Electric Light Association
American Electro Chemical Society
New York Electrical Society, and the
American Electric Railway Association.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted, which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alternators

Determination of Potential Drop in Polyphase Alternators. Bethenod, J. (In French.)
Revue Gen. de l'Elec., Nov. 18, 1922; v. 12, pp. 765-767.
(Short article of theoretical nature, based on the Blondel and the Potier diagrams, on determination of voltage drop under conditions of constant excitation and variable load.)

Blowers

Rotary Scavenging Blowers for Two-Stroke Marine Diesel Engines.
Engng. (Lond.), Dec. 1, 1922; v. 114, pp. 676-8.
(Illustrated description of BBC types of electrically-driven blowers.)

Coal, Pulverized

Powdered Coal as Fuel in Steam Plants. Kreisinger, Henry and Blizard, John.
Engrs. Soc. of W. Pa. Proc., June, 1922, v. 38, pp. 169-200.
(On furnace design and test results.)

Electric Cables

Voltage Limits in Impregnated Paper Cable. Del Mar, William A.
Elec. Wld., Dec. 9, 1922; v. 80, pp. 1257-1258.
("A summary of the technical problems in the manufacture of cable and an outline of the present methods for obtaining improvements.")

Electric Drive—Steel Mills

Alternating Current and Iron and Steelworks Practice. Hodges, J. Percy.
Elec'n (Lond.), Nov. 24, 1922; v. 89, pp. 597-600.
(Author points out advantages of a-c. drive.)

Electric Power in Iron and Steel Works. The Advantages of Generation and Transmission by Alternating Current Emphasised. Davidson, A.
Elec'n (Lond.), Nov. 24, 1922; v. 89, pp. 594-6.

Electrical Developments in Iron and Steelworks. Smith, James and Rothera, L.
Elec'n (Lond.), Nov. 24, 1922; v. 89, pp. 586-593.
(Illustrated account of British equipment and methods for roll drive and other electrical applications.)

Selection of Electrical Systems for Iron and Steelworks. Macsheehy, J.
Elec'n (Lond.), Nov. 24, 1922; v. 89, pp. 601-7.

Electric Furnaces

Electric Heating Applied to the Steel Industry. Hansen, F. A.
Assoc. Ir. & St. Elec. Engrs., Nov., 1922; v. 4, pp. 765-776.
(The author, who is Combustion Engineer, offers a general discussion of the various applications of ovens, furnaces, etc.)

Electric Power

Superpower Study in Pittsburgh District. Handy, William W.
Elec. Wld., Dec. 9, 1922; v. 80, pp. 1263-1267.

Electric Transformers

Portable Transformer for Arc Welding. Enfors, Erik. (In Swedish.)
Tekn. Tidskr., Nov. 11, 1922; v. 52, pp. 721-723.
(Description of the "Holslag" transformer of the Electric Arc Cutting and Welding Company, London.)

Electric Transmission Lines

Transmission of Energy without the "Return Wave." Boucherot, P. (In French.)
Revue Gen. de l'Elec., Nov. 18, 1922; v. 12, pp. 755-763.
(A theoretical discussion.)

Electrical Machinery—Losses

Power Losses in Insulating Materials. Hoch, E. T.
Bell System Tech. Jour., Nov., 1922; v. 1, pp. 110-116.
(Methods of testing and calculating to determine losses at high frequencies, such as in radio work.)

Electricity—Applications—Agriculture

Electro-Farming and Its Future. Matthews, R. Borlase.
Elec. Rev. (Lond.), Nov. 17, 1922; v. 91, pp. 737-739.
(Describes the author's plan for a completely electrified farm.)

Electricity—Theory

Heaviside Operational Calculus. Carson, John R.
Bell System Tech. Jour., Nov., 1922; v. 1, pp. 43-55.
(Mathematical paper.)

Electromagnets

Calculation of the Attraction of Electromagnets. Guilbert, André. (In French.)
Revue Gen. de l'Elec., Nov. 11, 1922; v. 12, pp. 714-718.
(Mathematical treatment simplifying the formula advanced by Perrot and Picou.)

Fuels

Selection of Fuel for Industrial Heating Operations. Doyle, Joseph A.
Steam, Dec., 1922; v. 30, pp. 153-161.
(Includes extensive charts showing the characteristics of various fuels.)

Heat Transmission

Transmission of Heat by Radiation and Convection.
Engng., Dec. 1, 1922; v. 114, pp. 672-673.
(From Special Report No. 9, Engineering Committee of the Food Investigation Board, London, on "Transmission of Heat by Radiation and Convection.")

Hydro-electric Development

Colorado River Treaty a Simple Document.
Elec. Wld., Dec. 9, 1922; v. 80, pp. 1294-1295.
(Gives full text of the Colorado River development agreement as subscribed to by the states of Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming.)

Fully Hydro-electric Power Station, Switzerland.
Engng., Nov. 24, 1922; v. 114, pp. 635-639.
(Illustrated description. Serial.)

Oscillographs

Low Voltage Cathode Ray Oscillograph. Johnson, J. B.
Bell System Tech. Jour., Nov., 1922; v. 1, pp. 142-151.
(Explains the construction and use of the instrument.)

Photography, Rapid

High-speed Photography of Vibrations (Sound Mechanical, Electrical, etc.). Trowbridge, Augustus.
Franklin Inst. Jour., Dec., 1922; v. 194, pp. 713-729.
(Describes the camera and its use.)

Power-factor

Cash Value of Power-Factor Correction. DeWeese, Fred C.
Elec. Wld., Nov. 4, 1922; v. 80, pp. 980-982.
(Shows the economies to be effected by power-factor correction.)

Improvement of Power-Factor. Kapp, Gisbert.
Engng., Nov. 24, 1922; v. 114, pp. 659-662.
(Paper before the Institution of Electrical Engineers, November 16, 1922. Serial.)

Power Plants, Electric

New Paris High-Pressure High-Temperature Central Station.
Mech. Engng., Dec., 1922; v. 44, p. 829-831.
(A summary of statistics on the equipment of the Gennevilliers plant, Paris. Refers to Mercier's descriptive pamphlet and to several periodical references on the same subject.)

Radio Engineering

Physical Theory of the Electric Wave-Filter. Campbell, George A.
Bell System Tech. Jour., Nov., 1922; v. 1, pp. 1-32.
(Explains the action of the wave filter for use in telephony, radio work, etc. Includes appendix showing the mathematical theory.)

Railroads—Electrification

Future of Railway Electrification and Its Connection with Power Supply and Distribution. Dawson, Philip.
Elec. Rev. (Lond.), Nov. 17, 1922; v. 91, pp. 742-745.
(A general summary of progress and possibilities in Europe and America.)

Roller Bearings

Roller Bearings Applied to Mill Motors. Hess, L. J.
Assoc. Ir. & St. Elec. Engrs., Nov., 1922; v. 4, pp. 739-763.
(Author is Chief Electrician, Youngstown Sheet & Tube Company.)

Ship Propulsion, Electric

Electricity in the Propulsion of Ships. Hobart, Henry M.
Elec. Rev. (Lond.), Nov. 17, 1922, v. 91, pp. 745-747.
(A general summary.)

Specifications—Welding Wire

Writing Specifications for Welding Wire. Knox, H. G.
Am. Weld. Soc. Jour., Nov., 1922; v. 1, pp. 47-50.

Standards

Second Revision of A. S. M. E. Boiler Code, 1922.
Mech. Engng., Dec., 1922; v. 44, pp. 850-856.

Size Standardization by Preferred Numbers. Hirshfeld, C. F. and Berry, C. H.
Mech. Engng., Dec., 1922; v. 44, pp. 791-800.
(Explains, by graphs and tables, the "preferred number" system of engineering standards of measurement.)

Test Code for Reciprocating Displacement Pumps.
Mech. Engng., Dec., 1922; v. 44, pp. 844-847.
(One of the 19 test codes of the American Society of Mechanical Engineers.)

Standards, Electric

Proposed Standards for Resistance Welding Transformers.
Am. Weld. Soc. Jour., Nov., 1922; v. 1, pp. 38-42.
(American Bureau of Welding proposed standards.)

Steam Boilers, Electric

Electric Steam Boilers for Using Surplus Water Power.
Elec. Wld., Dec. 2, 1922; v. 80, pp. 1211-1212.
(Illustrated description.)

Steam Plants

What Is a Heat Balance and How Is It Calculated? Darnell, J. R. and Binns, A. W.
Power Pl. Engng., Dec. 1, 1922; v. 26, pp. 1162-1165.

Steam Turbines

Bleeder Turbine as a Coal Conservator. Moore, J. L.
Ind. Man., Dec., 1922; v. 64, pp. 360-363.

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GENERAL
ELECTRIC
REVIEW

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE   Editor, JOHN R. HEWETT   [illegible]

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Fig. 2. Colored Image when Normal Inside Pressure Alone is Applied

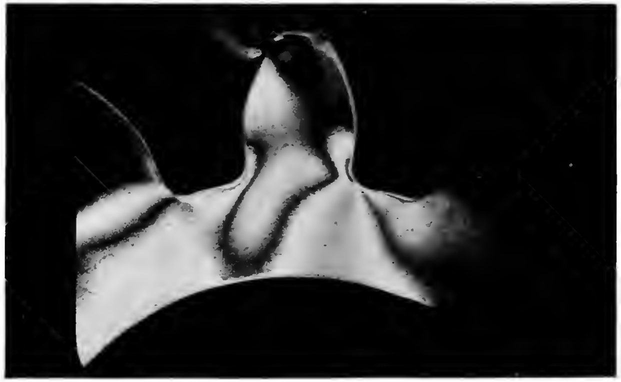

Fig. 5. Colored Image Obtained for Normal Inside Pressure and Reduced Torque

Fig. 3. Colored Image when Both Normal Inside Pressure and Maximum Torque are Applied

Fig. 4. Colored Image when Both Normal Inside Pressure and Maximum Torque are Applied

These illustrations are in connection with an article published in this issue on the Stress Distribution in Railway Motor Pinions as Determined by the Photo Elastic Method, using Transparent Celluloid Models. (The Fig. numbers are referred to in the text).

GENERAL ELECTRIC REVIEW

THE CONTROL OF POWER

Mr. Lawrence's article, published in this issue, on the Load Dispatching System of the New York Edison Company should convey to the reader a lesson not actually cited in the text. Forty years ago, as told in our December number, the first Edison station was put into commission. Since that day the power stations built have been legion. They have gradually increased in capacity until today some stations have an installed capacity of over a quarter of a million kilowatts and the individual generating units during this same period have increased from a few kilowatts per unit to the huge Titans of 50,000 kilowatts apiece.

The generation, distribution and control of electric energy has taken an extraordinary amount of scientific and technical knowledge, skill, courage and human energy to bring it to its present perfection.

The public really has no adequate mental conception of what the engineer has done for his country and for civilization by this work. Thirty years ago we pointed with pride to a power station of 2000 kilowatts capacity. Since that time each year has seen an increase in capacity, an extension of the use of electrical energy and an extension of the area covered, until today life in any large city is unthinkable without the distribution of electric energy. Continuity of service from the Public Utility is of more importance to the public than the continuity of any other civic function, yet small appreciation is shown.

A few years ago our small power stations were independent entities serving their own small circles. Today, as Mr. Lawrence describes, many power stations and numerous substations are interconnected together so that power can be re-routed in case of stress and emergency. The whole system of generating stations can be controlled by one operator from a central point. What this means to the public in the elimination of inconvenient delays is hard to overestimate.

What Mr. Lawrence describes applies to one of the largest cities in the world and its environments, but there is a greater conception which has more recently begun to bear fruit. In many districts we are working toward superpower zones where all the generating stations, both steam and hydraulic, will have their arteries interconnected together so that every unit station in this zone can serve any section of the community covered. This is a big step in advance. In the future when these superpower zones themselves have been interconnected we can begin to think that we are really nearing the accomplishment of one of our greatest duties, namely, to provide the whole country as far as possible with electric energy.

The tying together of these stations and of these zones will entail the control of an almost unthinkable amount of energy and the putting into use the machines by the millions for both manufacturing and domestic purposes. The economic life of the country will be satisfactory in just such a measure as we do this work.

The control of such a vast amount of energy would have been impossible a few years ago because in thinking of machines we must always be mindful of the nature of the machine.

> "But remember, please, the Law by which we live,
> We are not built to comprehend a lie.
> We can neither love nor pity nor forgive.
> And if you make a slip in handling us you die!
> We are greater than the Peoples or the Kings—
> Be humble, as you crawl beneath our rods.
> Our torch can alter all created things.
> We are everything on earth, except the Gods."
>
> —*Kipling*

There is no greater or more useful work that the large electrical corporations have done for this country, and for the world at large, than devising means and ways of controlling these huge amounts of energy efficiently and safely.

J. R. H.

Operating Pilot Board and Load Dispatching System of the New York Edison Company

By W. H. Lawrence

Superintendent Waterside Stations, New York Edison Company

The author describes in considerable detail the load dispatching pilot board of the New York Edison system. This load dispatching board enables the whole system, power station, substation, transmission line, feeders, etc., to be governed from one central point. It might be described as the master eye of one of the largest and most wonderful electric systems in the world.—Editor.

The load dispatching system, which centralizes the control of the operation of the entire system, was inaugurated by The New York Edison Company in 1902, shortly after Waterside No. 1, the first of the high-tension alternating-current generating stations of the Company, was placed in service. At that time, the pilot board consisted of a drawing board approximately 30 in. by 60 in. on which were indicated all oil switches in the generating stations and substations and the transmission cables. Opened and closed switches and "alive" and "dead" transmission cables were indicated by various colored tags hung on the board.

With the growth of the system, this board became inadequate and inefficient. It had been recognized for some time that a pilot board for system operation must function automatically to give instant and correct indications. It should not depend on the human element for the correctness of its indications. Such an automatic board was designed and installed in 1912 in Waterside Station No. 1. The importance of reproducing automatically, before the System Operator, indications of the operation of all oil switches in the generating stations was such that no expense was spared to incorporate on this board all the necessary automatic features. Such automatic indications are extremely valuable during emergencies when the System Operator may see at a glance the existing conditions of the system, the generators which are still connected to the busbars, the feeder switches which have opened and the connections which still exist between the various generating stations. From these indications, he is in position, without awaiting reports from generating stations and substations, to act immediately toward the resumption of normal conditions.

The pilot board at the present time is approximately 20 feet long and 9 feet high and is so constructed that it may be enlarged from time to time to take care of the growth of the system. At the present time, there are represented on the pilot board the four large generating stations of The New York Edison Company and allied companies: Waterside No. 1, Waterside No. 2, Sherman Creek, and Hell Gate, the two smaller stations, Kingsbridge and Jersey City, seventy-three substations, and all customers receiving high-tension energy. Fig. 1 shows a general view and Fig. 2 a small section of the pilot board.

The pilot board is mounted on steel framework with hollow metal trimming and consists of several hundred small slate panels, one for each group in the generating stations and one for each substation. The generating stations are indicated on the upper part of the board, the slate panels being arranged horizontally across the pilot board, and the panels representing the substations are mounted vertically on the lower part of the pilot board below the generating stations. The name of each substation is directly above its panel where also is given the total battery capacity of the substation at the one-hour rate. The pilot board as now equipped contains 3302 "bull's eye" telephone lamps and upon the completion of the Hell Gate Station, one half of which is now operating, will contain 3568 lamps.

For each generating station the number of slate panels corresponds to the number of groups of apparatus connected to the station busbars and are numbered correspondingly. A feeder group consists of two oil switches, one for each of the two transmission cables and two selector oil switches which connect the two feeders to either one of two sets of busbars. A generator group consists of the generator oil switch and two selector oil switches which connect the generator to either of the two sets of busbars. The section of buses are separated by white marble panels on which are indicated the bus tie oil switches. On each of the panels, each oil switch of the group represented is indicated by two "bull's eye" telephone lamps, one red and one green. The lamps indicating the selector switches are placed above and below the group numbers, the ones above indicating the main bus selector switches, the ones below the auxiliary bus

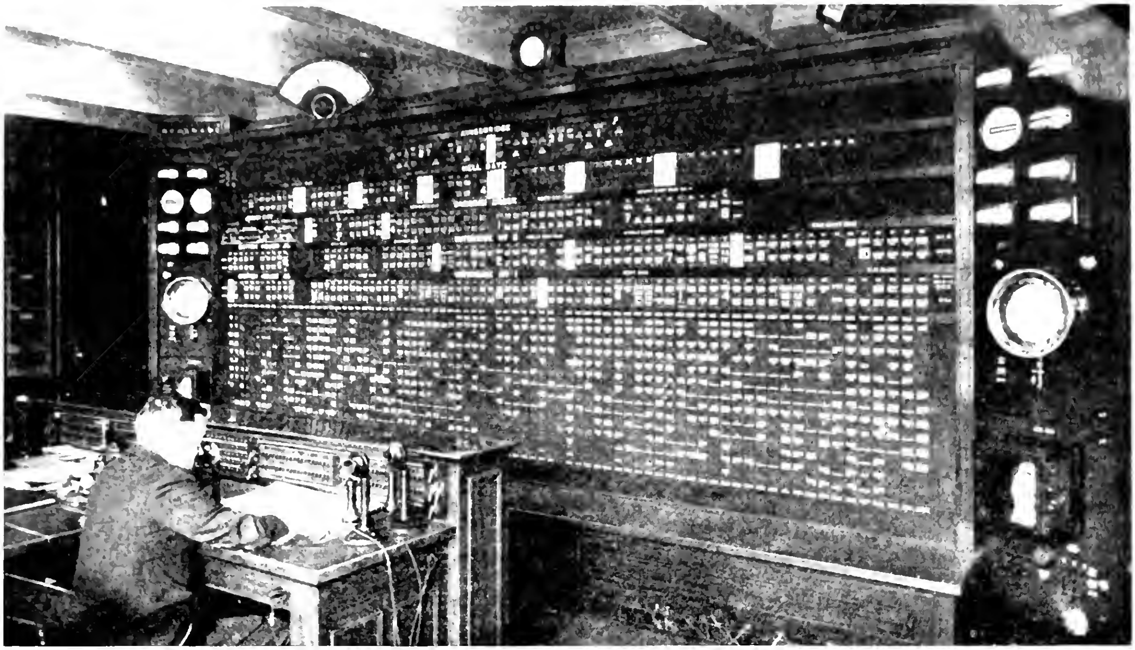

Fig. 1. General View of System Operator's Office

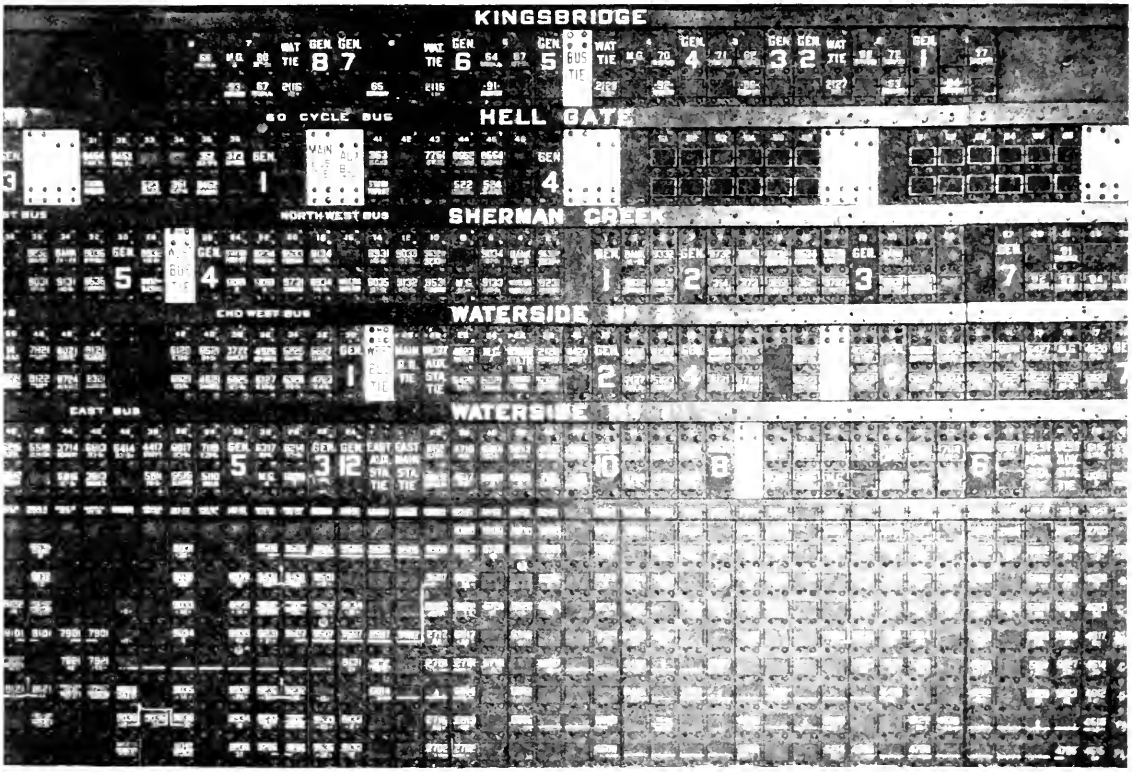

Fig. 2 Section of the Operating Pilot Board

selector switches. Card holders for numbering the apparatus represented are installed on all panels just above the indicating lamps. The direct transmission cables are represented in the substations by their respective numbers; below each number is connected in parallel a red "bull's eye" lamp and a telephone jack. The group number to which the feeder connects in the generating station is placed just below the feeder number. The red lamp and telephone jack of each direct feeder are connected to a local circuit operated by a relay which is connected to the secondary of a potential transformer, the primary of which is connected to the feeder cable on the street side of the feeder oil switch at the generating station. So connected, this lamp serves two purposes. First, it indicates when the feeder is "alive" from the generating stations; and second (when not "alive" from the generating stations), it indicates when the feeder is "alive" from substations due to inverted rotary converters, paralleled feeders, or mistakes in switching. Tie cables between substations are represented in the various substations to which they connect by the feeder number below which are red "bull's eye" lamps and telephone jacks. The lamps and jacks of each tie cable are all connected in parallel to one circuit. Connections in substations between direct feeder cables and substation tie cables are indicated by cords which are plugged into the jacks of the cables connected, the cord completing the circuit and lighting the red lamp in each substation to which the tie cable connects.

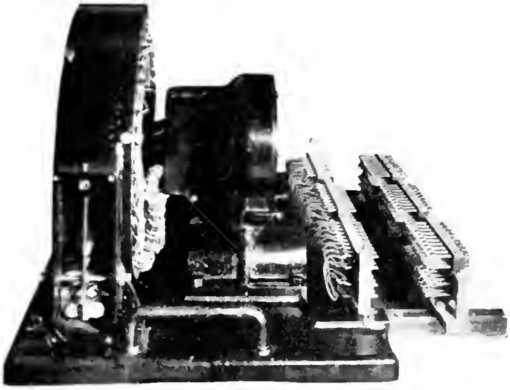

Fig. 3. View of Distributor showing Multiple Jack Method of Construction at Rear

Lines are drawn on the board to indicate the cables between substations and direct feeder cables which feed more than one substation. By placing below each feeder number the group number to which the feeder connects in the generating station, lines to indicate direct feeders are unnecessary and therefore are omitted. One terminal board is provided for the indicating lamps of each generating station and one for the indicating lamps of all substations, all lamps being permanently connected to their respective terminal boards. Terminal boards are provided for the relay wires, one for each generating station, so that by cross-connecting between the relay terminal board and the indicating lamp terminal board, any relay may be connected to any pair of indicating lamps, thus making it unnecessary at any time to change the wiring or the connections to the panels. Current to operate the board is supplied by two 3-kw. 30-volt motor-generator sets (one being reserve) which may be operated from the exciter system, the station lighting system, or from storage batteries. Standard 24-volt telephone lamps and red and green "bull's eye" lamp caps are used throughout.

Special contacts which operate the indicating lamps are installed on the top mechanism of each oil switch in the generating stations. In the Waterside stations, one wire is used between the special contacts of each oil switch and the corresponding indicating lamps on the pilot board, so connected that the green lamp is lighted when the oil switch is open and the red lamp when the switch is closed.

On each end of the board are instrument panels on which the voltmeters and frequency indicators of both systems are mounted. Indicating wattmeters to indicate interchange of energy between generating stations and curve drawing totalizing wattmeters for the two Waterside stations are also provided. On top of the board are totalizing indicating wattmeters indicating the load of each Waterside station.

To receive indications automatically of the operation of switches in the Hell Gate Station, approximately five miles from the pilot board, a 300-wire cable is used. In the Hell Gate Station these wires terminate in a terminal board where they are cross-connected to the wires leading to the special contacts on the oil switches, one wire being used for each oil switch. The other end of the cable terminates in a terminal board at the pilot board where the wires are cross-connected to polarized relays which operate the red and green lamps on the pilot board. This system is supplied from a 62½-volt positive and 62½-volt negative system with neutral and so connected that negative polarity operates the relays to light the red lamps and positive polarity the green lamps of the corresponding switches at Hell Gate Station. These relays are equipped with auxiliary contacts to give a bell alarm at the pilot board when a switch at Hell Gate operates.

A comprehensive system of numbering the transmission cables is employed. Each substation is given a key number of two figures and each generating station a key number of two figures. Each transmission cable is numbered with a number consisting of four figures, the first two figures being the key number of the substation in which the transmission cable terminates, the last two figures being the key number of the generating station from which the cable originates so that the number of a transmission cable indicates from which generating station the cable originates and at which substation it terminates. Tie cables between substations take the key number of the northerly substation, the last two figures of the number being the key number of tie cables. For instance, the key number of 26th Street substation is 58, the key numbers of Waterside No. 1 generating station are from 10 to 19 inclusive, and the key numbers of the Hell Gate generating station are from 50 to 59 inclusive. Therefore, feeder number 5814 is a cable from Waterside No. 1 to 26th Street substation and feeder 5856 is from Hell Gate to 26th Street substation.

To receive indications automatically of the operation of switches in Sherman Creek Station, approximately ten miles from the pilot board, a distributor system designed and installed by the Western Electric Company is used. See Figs. 3, 4 and 5. Four distributors are installed, two in Sherman Creek Station and two at the pilot board, each pair of distributors taking care of 100 switches and requiring, between Sherman Creek Station and the pilot board, three telephone wires for each 100 switches.

The distributor consists of a fibre disc to the face of which are mounted three sets of insulated segments and corresponding collector rings. The outer and inner rings of these segments are used for the switch indications and the inner ring to keep the distributors in synchronism.

As the circumference of the outer ring is twice that of the inner ring, every other segment of the outer ring is used, there being 50 switches connected to each ring of segments.

All segments and collector rings are traversed by a set of brushes mounted on brush arms and revolved at approximately 12 r.p.m. through a friction clutch and an arrangement of gears. The power to drive the brush arm is obtained from a 1/50-h.p. 115-volt direct-current motor. The speed of this motor is controlled by a centrifugal governor which may be adjusted during operation.

The distributors are used in pairs, one located in the Sherman Creek Station, the other at the pilot board. They are connected one to the other by three telephone lines, two of which are used to transmit the switch indications and one to keep the distributors in synchronism. See Fig. 6. Each distributor is a complete unit in itself, all connections being made by the multiple jack method of connection so that to change a distributor all that is necessary is to pull it out and push another one in place. A reserve distributor is carried at Sherman Creek and at the pilot board.

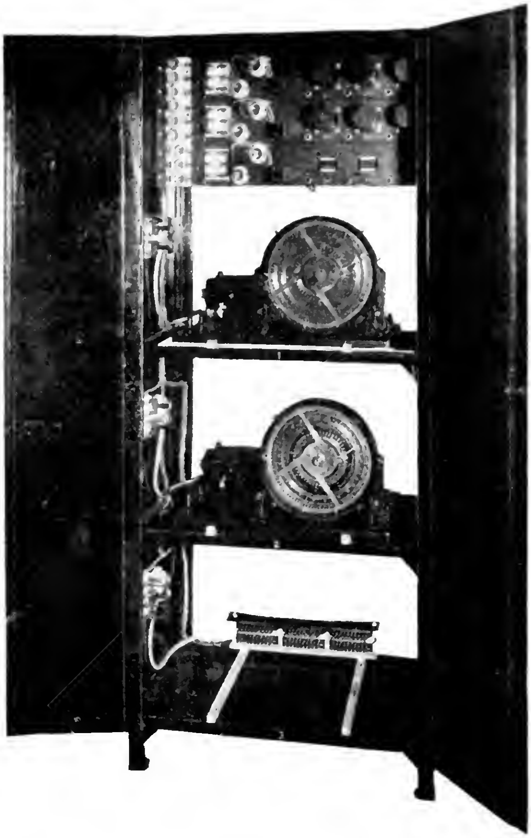

Fig. 4. View of the Cabinet showing the Two Distributors and Space for the Reserve

The segments of the distributors at Sherman Creek are connected to the special contacts on the oil switches, one wire being used for each oil switch. The contact on the oil switch is practically a single-pole double-throw switch, the center point of which is connected to the segment of the distributor, the other two points connected one to positive polarity and one to negative polarity. When the oil switch is closed negative polarity and when the oil switch is open positive polarity is transmitted to the distributor segment.

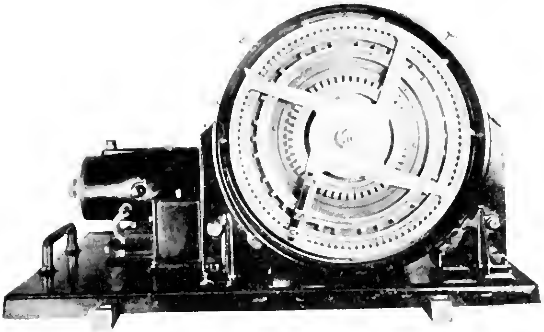

Fig. 5. Front View of Distributor Used for Obtaining Sherman Creek Switch Indications

The corresponding segments of the distributor at the pilot board are connected to polarized relays which operate the red and green lamps on the pilot board.

To maintain the two distributors in synchronism, there are ten segments on the middle ring separated by insulating material and bridged by the revolving brush to the collector ring, five of the segments of the pilot board distributor are connected to positive polarity and five to negative polarity. The ten segments of the Sherman Creek distributor are connected to ground.

On the periphery of the revolving element which carries the brush arm are five teeth so spaced as to be in alignment with the synchronism segments. Engaging the teeth are two release magnets 180 degrees apart.

The middle collector rings of the two distributors are connected through two polarized line relays in series, one located at the pilot board and one at Sherman Creek.

The release magnets are energized by the operation of the line relays, the right hand one of the pilot board operating with the right hand one of the Sherman Creek distributor and the left hand one of the pilot board distributor with the left hand one of the Sherman Creek distributor.

As the operating current is supplied to the pilot board distributor, this distributor may be called the master. As the brushes pass over the synchronizing segments impulses are sent through the two line relays in series, through the brush to the synchronizing segments of the Sherman Creek distributor.

The operation of the line relays completes the circuit through the release magnets and disengages them from the teeth of the revolving brush elements. The brushes then pass over segments of insulation interrupting the current supply to the line relays and resetting the release magnets to engage the teeth of the revolving brush element.

The distributors are thus synchronized ten times during each revolution and as the teeth on the brush arms are in alignment with the synchronizing segments, the release magnets will be energized before the teeth engage with the release magnets, provided the distributors are in exact synchronism.

If, however, the two distributors are not in exact synchronism, and one is slightly ahead of the other, this one will be stopped by the release magnet until the slower one comes into synchronism, when the release magnet will operate, releasing the brush arm and allowing it to continue revolving.

All of the green lamps on the pilot board of switches not in service are capped so that normally no green lamps are exposed lighted, the red lamps of course being lighted for all closed switches. During any emergency when one or more switches in any of the generating stations opens automatically or is opened by switchboard operators, the red lamps corresponding to such switches are extinguished and the green lamps lighted. At the same time, the bell alarm rings, calling the System Operator's attention to the pilot board, where at a glance he is enabled to see exactly what equipment has been thrown out of service.

It is the function of the System Operator, in his control of the operation of the system, to apportion the load among the several generating stations and keep in reserve at all times sufficient generating equipment, transmission and transforming equipment to take care of any demand which the system may be called upon to meet. No apparatus, therefore, is taken out of service without first obtaining the approval of the System Operator. The system is called upon to meet extraordinary and sudden demands during the summer when thunderstorms occur. The load during such storms increases rapidly and often exceeds 100,000 kw. above normal day load (Fig. 8).

The System Operator, further, is charged with the responsibility of protecting all high-tension equipment that men are engaged in working on against the possibility of such equipment becoming "alive." It is his duty to direct that such apparatus, where necessary, be grounded, oil switches blocked open, etc.

A special telephone switchboard is located directly in front of the operating pilot board. From this switchboard radiate direct telephone lines to each substation and to each generating station of the system. In addition to the direct telephone lines, several exchange lines are also connected to the board. The board normally is a two-position board but is so wired that in cases of emergency, by throwing keys, the board may be split into six parts so that six operators may use it at one time if desirable. Extraordinary precautions are taken to maintain this telephone system. "Taking" current may be received from either of two telephone exchanges or from a storage battery located at the switchboard. "Ringing" current may also be obtained from either of two telephone exchanges or from magneto equipment on the switchboard. The telephone lines leaving the switchboard are divided over three cables to two telephone exchanges, taking different routes through the building and through the streets.

To further increase the efficiency of the system operation and to establish, during emergencies, more speedy means of communication with the substations than is possible with telephones, a signaling system consisting of standard Gamewell Fire Alarm apparatus is used between the System Operator and all of the substations and generating stations, using for circuits leased lines of The New York Telephone Company. See Fig. 7. The signaling switchboard, which has a capacity of sixteen circuits, ten of which are used at the present time, is located in the System Operator's Office. This switchboard consists of the master sending device, voltmeters, testing plugs, circuit indicating lamps, balancing resistors, multiple punch recorders, which record on paper tape all signals sent, the circuits over which they are sent and an automatic time stamp which prints on the paper tape the date and time that signals are sent.

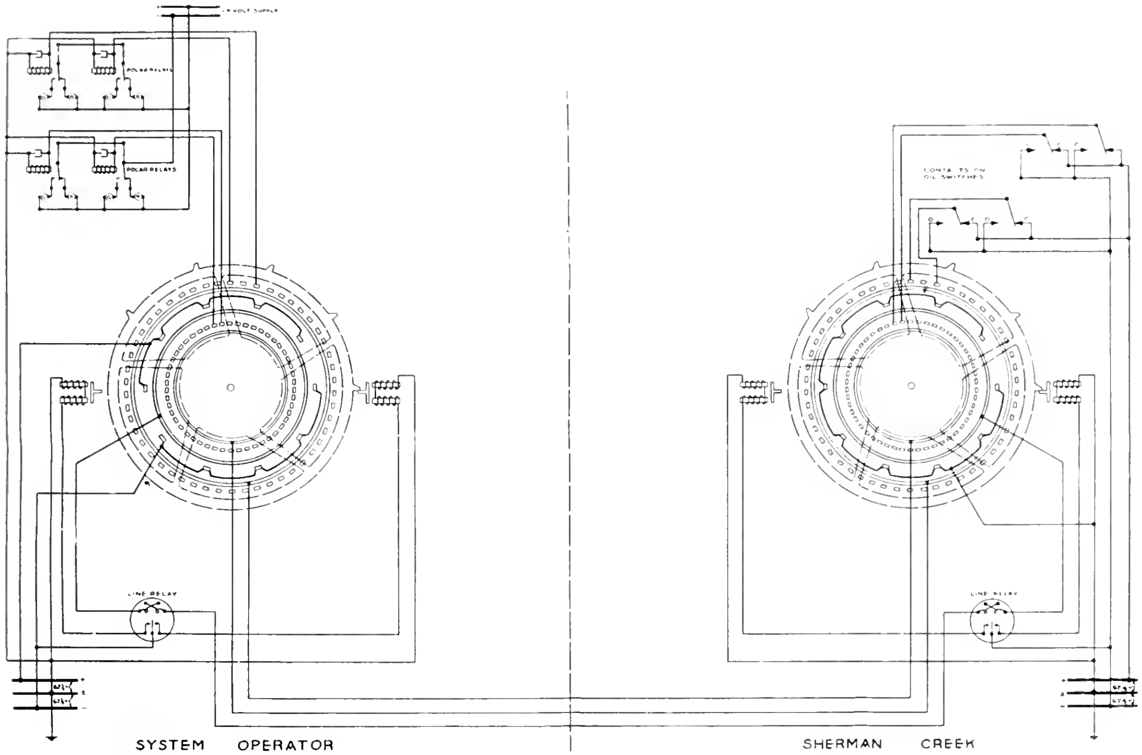

Fig. 6. Switch Indicating System Between Sherman Creek Generating Station and System Operator's Pilot Board

Several substations, the number depending on circuit lengths, are connected to each circuit. By means of circuit switches, signals may be transmitted to an individual circuit or to any combination of the circuits. Current to operate this system is supplied by 120-volt motor-generator sets installed in duplicate and to insure uninterrupted service they may be operated either from the station lighting system, the excitation system, or the storage batteries. The equipment is of the closed circuit type so that by means of indicating lamps connected by relays to the circuits, the continuity of each circuit is indicated continuously.

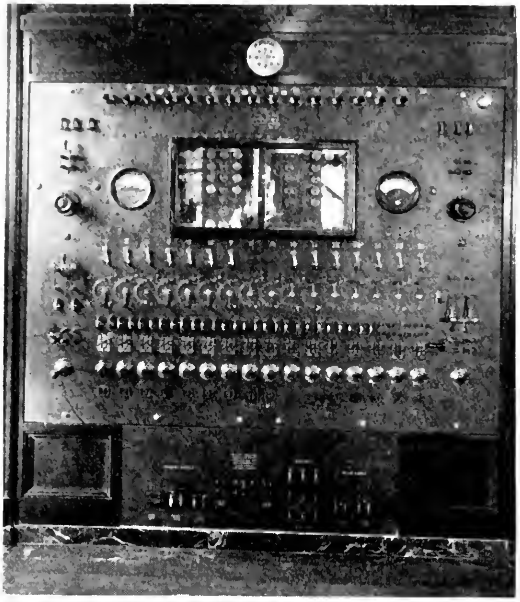

Fig. 7. Control Switchboard of the Emergency Signal System

For each signal there is provided a wheel with notches corresponding to the signal number cut into its periphery. To send a signal, the circuit switches of the circuits over which it is desired to send the signal are closed, the signal wheel placed on the shaft of the sending device and the sending lever pulled. The entire operation requires from 5 to 10 seconds. The sending device is equipped with a repeating lever by which signals may be repeated from two to four times as desired. Under the present system of operation this lever is set to repeat all signals three times. The substation equipment consists of a 10-inch electro mechanical gong and a punch recorder mounted on the substation switchboard near the substation switchboard operator. In order to test this system daily, a time signal—12 o'clock noon—is sent over all of the circuits and all clocks are set in accordance with this signal. A set of instruments installed in the Executive Offices of the company records all signals sent by the System Operator and enables the executives to keep in close touch with the operating conditions during emergencies.

The advantages of this system, which under the present method of operation is used during emergency conditions only, may be summarized as follows:

1st: The System Operator is relieved of telephoning instructions to the substations individually as he is enabled to signal the instructions simultaneously to all substations in less than one minute with the result that simultaneous action and cooperation of all substations are obtained.

2nd: The substations, by receiving signals that the disturbance or emergency is general and not local, are enabled at once to adopt the proper course of action.

3rd: Instructions issued by the System Operator are recorded.

4th: Instructions are transmitted accurately, avoiding the liability of misunderstanding telephone instructions. The present code of signals applying to the 25-cycle system is as follows:

1 2	Transfer half of your load on Waterside No. 1 feeders to Waterside No. 2 feeders.
1 3	Transfer half of your load on Waterside No. 2 feeders to Waterside No. 1 feeders.
1 4	Transfer half of your load on Hell Gate feeders to Waterside No. 1 and Waterside No. 2 feeders.
2 2	Trouble at Waterside.
2 3	Indications of trouble—"Stand By."
2 4	Trouble at Hell Gate.
2 5	All alternating-current supply is interrupted.
2 6	Indications of approaching storm.
3 1	Discharge all batteries at the one-hour rate and drop load off Waterside No. 1 feeders.
3 2	Discharge all batteries at the one-hour rate and drop load off Waterside No. 2 feeders.
3 3	Discharge all batteries at the one-hour rate and drop load equally off Waterside No. 1 and Waterside No. 2 feeders.
3 4	Discharge all batteries at the one-hour rate and drop load off Hell Gate feeders.

3 1 3 Discharge all batteries at the three-hour rate and drop load off Waterside No. 1 feeders.
Note.—Upon receipt of this signal if discharging at the one-hour rate pick up reduced battery load on Waterside No. 1 feeders.

3 2 3 Discharge all batteries at the three-hour rate and drop load off Waterside No. 2 feeders.
Note.—Upon receipt of this signal if discharging at the one-hour rate pick up reduced battery load on Waterside No. 2 feeders.

3 3 3 Discharge all batteries at the three-hour rate and drop load equally off Waterside No. 1 and Waterside No. 2 feeders.
Note.—Upon receipt of this signal if discharging at the one-hour rate pick up reduced battery load equally on Waterside No. 1 and Waterside No. 2 feeders.

3 3 4 Discharge all batteries at the three-hour rate and drop load off Hell Gate feeders.
Note.—Upon receipt of this signal if discharging at the one-hour rate pick up reduced battery load on Hell Gate feeders.

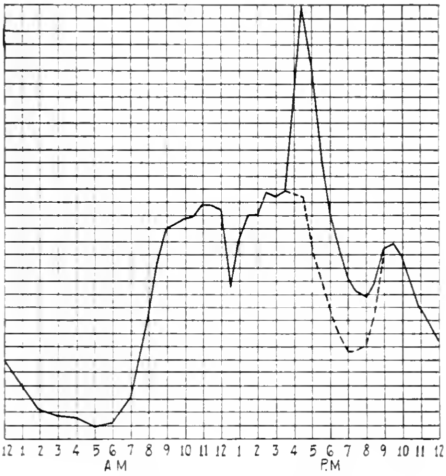

Fig. 8. Summer Load Curve showing Effect of Storm. Dotted line is for a normal day

4 1 Clear all feeders which are not carrying load and promptly notify System Operator when clear.

4 2 Connect rotaries to start from a "Stand Still" and promptly notify System Operator when ready.

4 3 Waterside and Hell Gate [illegible] start

4 4 Trouble now O. K.

4 6 Conditions satisfactory

4 7 Conditions normal.

5 1 Lower pressure on all d-c. feeders 10 volts a side

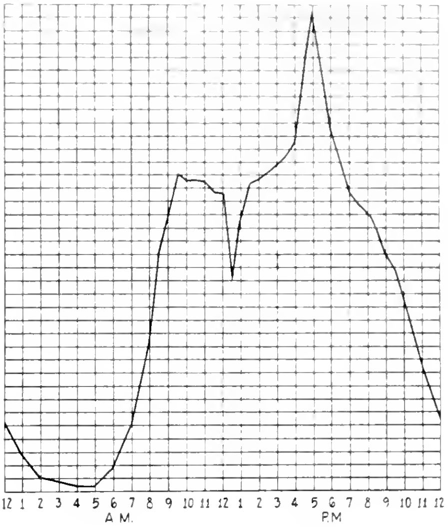

Fig. 9. Winter Load Curve

5 2 Disconnect all batteries from the d-c. system.
Note.—Reconnect the batteries to system when voltage of system is such that they will not discharge when floating on lowest end cell.

5 3 Waterside and Hell Gate will now lower a-c. voltage.

5 4 Restore d-c. pressure to normal.

6 1 Interruption probably of short duration, less than 5 minutes.

6 2 Interruption probably of long duration, more than 30 minutes.

6 3 Interruption of unknown duration.

6 6 Time signal—Correct time is 12 o'clock noon.

6 7 Test signal

7 7 Cancel last signal.

The storage battery capacity of the Edison direct-current system is today approximately 60,000 kw. for one hour. By means of this system, the generating stations may obtain relief of 60,000 kw. in from one to two minutes which would be impossible if it was necessary to telephone each substation for battery discharges.

The New York Edison and allied companies serve the territory within the Boroughs of Manhattan, Bronx and Queens and of Westchester County. The direct-current distribution system covers the Borough of Manhattan south of 135th Street. The alternating-current distribution system covers the balance of the territory mentioned above. To supply this territory there are four large high-tension generating stations and several smaller stations having an aggregate installed capacity of 456,000 kw. 25 cycle and 233,000 kw. 60 cycle, a total installed capacity of 689,000 kw. To supply the direct-current distribution system which lies south of 135th Street in the Borough of Manhattan, there are thirty-two rotary converter substations and to supply the alternating-current distribution territory there are twenty-seven alternating-current substations. To supply the railroad service which is supplied by the allied companies, there are thirteen direct-current substations and one alternating-current substation.

For the interchange of power with other companies in Greater New York, there are connections between the system of The New York Edison Company and the Interborough Rapid Transit Company, the Brooklyn Edison Company, the Brooklyn Rapid Transit Company, and the Pennsylvania Railroad Company, having an aggregate capacity of approximately 68,000 kw.

Atmospheric Nitrogen Fixation

PART I

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

The essential need of nitrogen in our modern civilization is now becoming generally recognized. It is a necessary element in plant food and explosives. It is used extensively in the production of celluloid, dyes, many drugs, perfumes, flavorings, etc. In Part I, this month, the author deals with the need for nitrogenous fertilizers, the nitrogen cycle in Nature, Chile saltpeter, by-product ammonia and the arc process of producing nitrogen from the atmosphere. In Part II the cyanamid, cyanide, nitride, Haber and Claude processes will be dealt with. This article originally appeared in the *Gas Age-Record*.—Editor.

The three essential food constituents of living matter are carbohydrates, fats and proteins; the two former chiefly for the production and storage of energy and the latter for building up the body substance. They are alike in the respect that they all contain the three elements carbon, hydrogen and oxygen, but differ in that protein also contains nitrogen, which, therefore, becomes one of the indispensable substances of life.

Nitrogen is a colorless, tasteless and odorless gas, slightly lighter than air. It comprises about four-fifths of the volume of the atmosphere, where it occurs in a free state mechanically mixed with oxygen. In this free state, it is an exceedingly inert element and combines only with difficulty with certain other elements as will be explained later. In combined form, it is found chiefly in certain natural nitrate deposits, and natural manures such as guano also contain large quantities of nitrogen compounds.

Free Nitrogen

The atmosphere is the inexhaustible source for our nitrogen supply and every bit of nitrogen in plants, animals, and the soil has originated from free atmospheric nitrogen. Arrhenius estimates that no less than 400,000,000 tons of nitrogen are annually withdrawn from the atmosphere and as nitrogen does not accumulate to any great extent in the soil, this enormous quantity must again be set free as inert nitrogen gas by the decomposition of organic matter and restored to the atmosphere. An immense and endless circulation of nitrogen is therefore continually going on, as shown in the accompanying diagram.

Through the action of electrical discharges of thunderstorms, which continually go on in the atmosphere, appreciable amounts of free nitrogen in the air are converted into oxides of nitrogen which are absorbed by falling rain water and enter the soil in the form of nitric acid. This nitric acid then combines with the bases in the soil, such as potassium, calcium, etc., and forms the corresponding nitrates in which form they are taken up by the plants and metabolized into protein.

Through the action of bacteria in their root nodules, certain legumes, such as peas, beans and clover, also possess the capacity of directly absorbing free nitrogen from the air during their growth and converting it into protein.

It has thus been shown how the nitrogen is supplied to the plants and protein metabolized which serves not only as their own food supply but also as reserve food for the plants' off-springs. This now becomes animal food and, for vegetable eating animals, it is the sole source of the nitrogen for animal protein.

Part of the nitrogen which is not used for maintaining the body substance of animals is eliminated as urea, and hippuric acid, and from the urea much nitrogen is set free by the action of nitrous acid. This urea and hippuric acid together with decayed vegetable and animal matter, that is dead protein, is then with the aid of bacteria converted into ammonia. Part of this is by means of oxidizing bacteria converted into nitric acid and nitrate in which form it again is partly assimilated by the plants. Part of this nitrate is, however, dinitrified by bacteria, one portion reverting into free nitrogen which goes back to the atmosphere, the other being converted into ammonia which fails to oxidize and is volatilized as a gas, which is absorbed by rain and again returned to the soil. Part of the ammonia is also taken up directly by the plants from the soil.

Need for Fertilizers

The fertility of the soil would thus remain practically unchanged if all the ingredients removed in the various farm products were returned to the land where they come from. This is to some extent accomplished by feeding the crops grown on the farm to animals, carefully saving the manure and returning it to the soil. A careful study of the present conditions of farming indicates, however, that as a rule the manure produced on the farm is far from sufficient to maintain its fertility and artificial fertilizers must be resorted to.

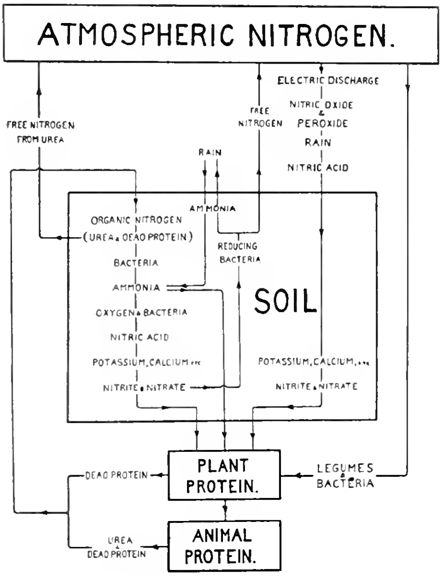

Fig. 1. Elementary Diagram of Nature's Nitrogen Cycle

It has been estimated that the yearly loss of nitrogen from soils under cultivation in this country by grain crops alone amounts to over 2,000,000 tons per year. Of this, not over three per cent is at present being supplied from organic fertilizer sources, such as tankage, cotton seed, etc., and this supply is constantly diminishing. The remainder must, therefore, come from inorganic materials. It would, of course, not pay to fertilize to the above extent immediately, but it merely indicates the extent to which nitrogen is needed for fertilizer purposes.

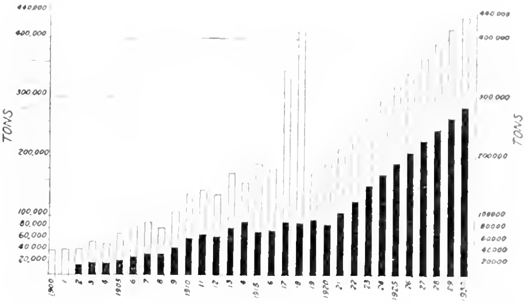

Fig. 2. Inorganic Nitrogen Consumption in United States as given by Nitrate Division of the United States Ordnance Department. Black portions represent inorganic nitrogen used in agriculture. White portions represent nitrogen used in industries and for explosives

With our constantly increasing population, an increased food supply must be provided and this can only be assured by increased cultivation and fertilization of the soil. How far behind we lag in this respect as compared with certain European countries, which of necessity have been forced to an intensive use of fertilizer, is shown by the following table. Prior to the increased use of fertilizer in these

Country	Pounds Fertilizer Used Per Cultivated Acre	AVERAGE YIELD IN BUSHELS PER ACRE, 1905-1913			
		Wheat	Rye	Oats	Potatoes
United States . . .	37	14.6	16.0	29.5	95.0
France	111	20.2	16.9	30.6	130.7
Germany	207	30.9	27.4	53.6	204.8
Great Britain . . .	244	33.4	29.1	43.5	211.7
Belgium	495	37.0	34.7	71.5	306.0

countries, the productivity of their soil was similar to our own, and the increase in their food supply, without additional labor and at a cost wholly incommensurate with the gains, has grown in direct proportion to the amount of fertilizer used.

Besides fertilizers, large amounts of nitrogen are also needed for industrial purposes, and the requirements to meet this demand are also steadily increasing.

Nitrate is one of the main ingredients in high explosives and gun powder, and nitration, that is, the treatment of substances with nitric acid, is the fundamental chemical operation in the production of gun cotton for making smokeless powder, celluloid or other pyroxylin plastics from cotton or paper such as artificial ivory, etc. The dye industry is also to a great extent based on nitration, and numerous drugs, perfumes and flavoring extracts are also being made in this manner from the coal tar bases benzol, toluol and naphthalene.

It is difficult to predict with accuracy to what extent the nitrogen fixation in this country will increase in the future. From statistics presented at a hearing before Congress in 1920, it was estimated that the possible consumption of fixed inorganic nitrogen would be as follows:

	1925	1930
Agriculture.......	190,000 tons	290,000 tons
Industries........	130,000 tons	150,000 tons
Total........	320,000 tons	440,000 tons

To supply this need, it is further estimated that the available production from by-product coke ovens will be:

	1925	1930
By-product oven production......	130,000 tons	160,000 tons

The difference would then have to be supplied by importation of Chile saltpeter or by increased products from atmospheric nitrogen fixation plants. For this latter purpose, there are now three plants in this country which with certain modifications would be available and with a combined yearly production capacity equivalent to about 45,000 tons of fixed nitrogen per year. At present only one of these plants is in operation with a yearly output of only a few thousand tons.

From these figures, it is obvious that we will have to continue to rely to a great extent on the importation of Chile saltpeter, unless steps are taken for providing increased facilities for fixation of atmospheric nitrogen. It is the purpose of this article to describe the different processes which at present are available for this purpose, but first a brief reference will be made to the other two sources of inorganic nitrogen, viz., Chile saltpeter and by-product ammonium sulphate.

CHILE SALTPETER

Chile saltpeter is chemically known as Sodium Nitrate ($NaNO_3$), the commercial product containing about 95 per cent nitrate of which 15½ per cent is nitrogen. Like the potash deposits in Germany there are few natural deposits like the saltpeter deposits in Chile on the west coast of South America. These deposits were discovered by Indians about 1809, who, when lighting a fire, noticed that the ground began to ignite in various directions. They attributed this to evil spirits and consulted a priest, who caused the earth to be examined, thus revealing the presence of nitrate of soda.

The nitrate deposits are located at altitudes ranging from 2000 to 6000 feet in the desert regions between the 12-degree and 26-degree latitudes, a distance of about 500 miles, and perhaps the driest country in the world, with no vegetation whatever.

The nitrate beds generally form horizontal layers covered by three distinct layers or strata of silica, calcium sulphate and other minerals, the thickness of these layers ranging from two to several feet. The nitrate as mined goes under the name "Caliche," and the deposits vary in thickness from a few inches to four or five feet or more. It is like a cemented gravel, the cementing material being the sodium nitrate and sodium chloride and other salts which accompany it. The caliche treated runs from 14 per cent nitrate up to as high as 30 per cent or more, and it does not as yet pay to mine materials with less than 13 to 14 per cent nitrate.

There are many theories advanced regarding the origin of these natural nitrate deposits. Some think that they are original guano deposits; others ascribe their origin to seaweed, because the caliche contains considerable amounts of iodine and fish skeletons are often found imbedded in the strata. Recent theories are that it has its origin in volcanic actions.

Preparation of the Nitrate

The production of Chile saltpeter comes under two divisions—the mining of the caliche and the refining. The caliche is extracted from the ground by blasting and hand picking, after which it is loaded in carts or light railroad cars and hauled to the refining plants called "oficinas," by mules or small locomotives. At the plant it is crushed and leached with boiling water, when due to the different solubility of the nitrate and chloride salts, practically all the nitrate will be dissolved while the other salts if already in solution will be precipitated. The solution is then allowed to cool and due to the solubility characteristics mentioned above the nitrate crystallizes out first while the other salts remain in the solution which is drained off. The nitrate, now in solid form, is placed in drying pans to allow the remaining water to evaporate and when entirely dry it is packed in bags of about 200 lb. each and shipped by rail down to the different harbors for export.

Most of the Chile saltpeter is used for fertilizer purposes, the nitrogen contained therein being extremely soluble and readily available as food for plants. The nitrogen in this form is thus directly and immediately available and no further changes are necessary.

Considerable amounts of Chile saltpeter are also used for industrial purposes in which case it must be converted in some other form, the starting point as a rule being nitric acid. This conversion is accomplished by treating the sodium nitrate with sulphuric acid, when a violent reaction takes place with the result of the formation of nitric acid which is given off as a gas. This passes into condensers where it is condensed to liquid acid. The reaction takes place according to the formula:

$$Na\,NO_3 + H_2\,SO_4 = HNO_3 + Na\,HSO_4.$$

Statistics

Chile saltpeter was first exported from Chile in 1830 but the amount was small, only a few thousand tons per year. Then it has, however, constantly increased as seen from the foregoing tabulation, which also [illegible] the export to the United States and its equivalent nitrogen content.

Year	Total Export in Tons	EXPORT TO UNITED STATES	
		Tons Nitrate	Tons Equivalent Nitrogen
1913	3,000,000	700,000	110,000
1914	2,700,000	605,000	95,000
1915	1,900,000	865,000	135,000
1916	2,200,000	1,360,000	214,000
1917	3,600,000	1,680,000	264,000
1918	3,200,000	2,075,000	325,000
1919	1,000,000	450,000	90,000
1920	3,000,000	1,430,000	224,000

It is interesting to note how the export dropped in 1915, when the supply of the Central powers in Europe was cut off, and how it since steadily increased until the end of the war when it again took a big drop.

The proceeds obtained from the export duty imposed by the Chile Government amounts to about 40 per cent of that country's yearly revenue.

The question is often asked: How long will the Chile deposits last? There is quite a difference of opinion in regard to this. It is estimated that the contents of the surveyed areas contained about 300,000,000 tons of nitrate of which about 50,000,000 tons have been mined, leaving about 250,000,000 tons untouched. At the present rate of production this would last about 100 years. It is claimed that the unsurveyed areas are some thirty times larger than the surveyed ones, but undoubtedly of a much lower nitrate content, and it is quite safe to assert that the deposits would last another 250 or 300 years. On the other hand, it is almost certain that long before that time new artificial nitrogen fixation processes will have been developed, by means of which it will be possible to manufacture nitrogen compounds at a much lower cost than the cost of Chile saltpeter, so that the mining of Chile saltpeter will undoubtedly be very materially curtailed long before these deposits are exhausted.

BY-PRODUCT AMMONIA

The by-product coke oven industry now occupies a vital place for the supply of nitrogen in the form of ammonia. Besides ammonia, the carbonization of the coal in these ovens gives us many other valuable by-products such as benzol, toluol and naphthalene.

It is interesting to watch how these modern by-product coke plants rapidly supersede the

PRODUCTION IN UNITED STATES

Year	By-product Coke		Beehive Coke	
	Tons	Per Cent of Total	Tons	Per Cent of Total
1901	1,180,000	5	20,615,000	95
1907	5,610,000	14	35,170,000	86
1913	12,715,000	28	33,585,000	72
1916	19,070,000	35	35,465,000	65
1918	26,000,000	46	30,480,000	54
1919	25,170,000	56	19,650,000	44
1920	30,835,000	60	20,510,000	40
1921	19,920,000	78	5,560,000	22

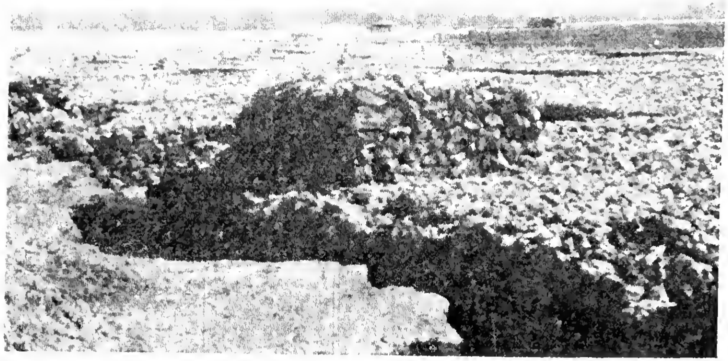

Fig. 3. Typical Nitrate Beds in Chile

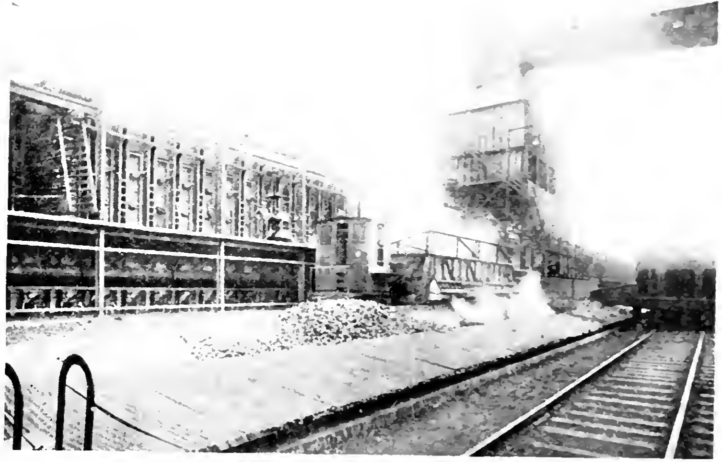

Fig. 4. By-product Coke Ovens, showing the Coke Being Removed from an Oven to the Quenching Car

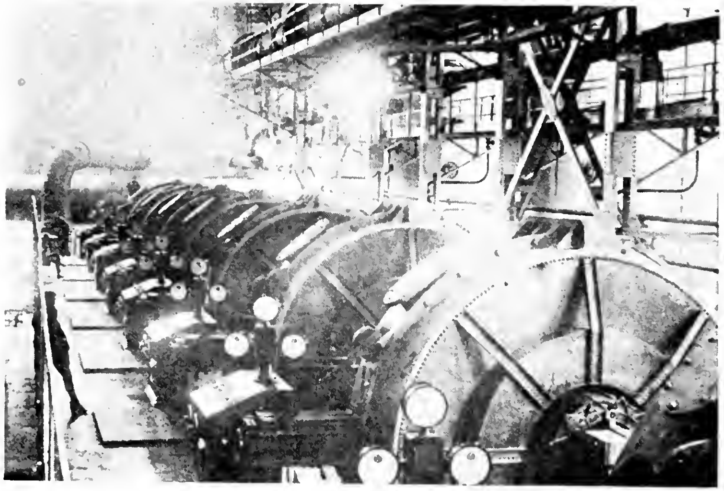

Fig. 5. Group of 4000-kw. Birkeland-Eyde Arc Furnaces at the Rjukan Nitrogen Works in Norway

Fig. 6. General View of the Rjukan Nitrogen Works in Norway

old-fashioned beehive ovens, as may be seen from the foregoing tabulation.

A by-product coke oven is a rather complicated structure, but briefly it consists of a large number of parallel chambers or ovens in which the bituminous coal is heated out of contact with the air. The ovens are separated by flues in which part of the gas generated by the distillation is burned to provide the heat necessary for the coking.

It is from the volatile matter in the coal given off that the by-products are obtained. The ammonia is thus the result of the union of nitrogen and hydrogen, according to some reaction which is not fully known.

The coal contains from 1 to 1½ per cent nitrogen, and of this only about 15 per cent is recovered in the form of ammonia. This means that we only get about 7 lb. of ammonia per ton of coke. The hot gases from the ovens containing the ammonia are cooled and scrubbed with water to remove the tar. They then go to saturators filled with sulphuric acid, and when the gas bubbles through this acid an intimate contact is established between the two and ammonium sulphate is precipitated as a solid salt according to the reaction:

$$2\,NH_3 + H_2SO_4 = (NH_4)_2\,SO_4$$

The ammonium sulphate thus formed in the saturators is then drained and dried in centrifugal driers, after which it is ready for sale. It then contains 24 per cent of ammonia, equivalent to about 20 per cent of nitrogen.

The remainder of the gas, now freed from ammonia, after leaving the saturators may then be further scrubbed with absorbent oils for recovery of other by-products, and if the gas is to be used for municipal purposes it must be further purified by removing any sulphur that it may contain.

Production Capacity

The annual productive capacity of the country's existing by-product coke oven plants is said to be about 35,000,000 tons of coke, which would correspond to a maximum ammonium sulphate output of about 550,000 tons, equivalent to 110,000 tons of combined nitrogen.

The ammonium sulphate production is, however, closely related to the steel mill business, and the recent slack in this industry was clearly reflected in the coke production, and naturally also the ammonium sulphate output as shown in the foregoing tabulation.

Year	Coke-oven Ammonium Sulphate Production in U. S. in Tons	Equivalent Nitrogen
1910	116,000	23,000
1911	127,000	25,000
1912	165,000	33,000
1913	195,000	39,000
1914	183,000	37,000
1915	250,000	50,000
1916	288,000	59,000
1917	370,000	74,000
1918	388,000	78,000
1919	423,000	85,000
1920	503,000	100,000
1921	346,000	69,000

THE ARC PROCESS

The principle underlying this process is the possibility of chemically uniting part of the free nitrogen and oxygen in the air at such high temperatures which only the electric arc is capable of producing, this being around 5000-6000 deg. Fahr.

Air, which is only a mechanical mixture of nitrogen and oxygen, is thus passed through an electric arc furnace when a small part (about two per cent) of these elements combine chemically and from nitric oxide, NO. This gas, when leaving the furnace, has a temperature of around 1500-1800 deg. Fahr., and in order to prevent the NO from dissociating or breaking up it must be rapidly cooled to a temperature around 100 deg. Fahr., which is done in two steps. The hot gas is first passed through ordinary steam boilers, which thus serve as coolers with recovery of heat in the form of steam for use in other parts of the process. The temperature of the gas is lowered to about 300 deg. Fahr. by these boilers, but below this point it becomes necessary to carry out the further cooling in aluminum coolers through which water circulates, without, of course, coming in direct contact with the gas. The reason for this is the fact that nitric oxide at these low temperatures, in the presence of moisture in the gas from water leaking through the tubes, begins to oxidize to nitric acid, which corrodes iron but not aluminum.

From the aluminum coolers the gas mixture is now conveyed to an oxidation chamber, a big sheet steel tank lined with fire brick. The purpose of this oxidation tank is to give the gas sufficient time to oxidize the nitric oxide NO to nitrogen peroxide, NO_2 or N_2O_4, this being desirable for the absorption of the gas which is to follow.

From the oxidation tank the gas is carried through an absorption system consisting of several groups of absorption towers, usually five towers in series per group. These towers are of enormous size, the inside being filled with lumps of quartz or other materials which the acid will not attack. Water is admitted to the top of the third tower and when it trickles down over the quartz filling it meets the ascending gas, and is converted into a weak nitric acid. This acid is then pumped to the top of the second tower where it is used as the absorption liquid and similarly the acid from the second tower is used for absorption in the first tower, thus gradually increasing in strength. After having thus passed the third tower, about 80 per cent of the NO_2 gas has been absorbed, and this is about all that can be absorbed by water, the resulting acid from the first tower having a strength of 30 per cent, this being known as weak nitric acid.

The reaction which thus has taken place in the three first towers is as follows:

$$3\,NO_2+H_2O=2\,HNO_3+NO$$

The liberated nitric oxide, in the presence of oxygen and water, is again converted into nitrogen peroxide and nitric acid.

The remaining 20 per cent of the gas leaving the third tower is now so weak that another solution than water must be provided for its absorption. An alkali solution such as soda ash is used for this purpose in towers four and five, the resulting product being a mixture of sodium nitrate and sodium nitrite, which is evaporated and may be used directly as a fertilizer. If only sodium nitrite is desired the gas is passed into a solution of caustic soda.

The weak acid from the first tower is, however, the main product; but as such a weak acid cannot be economically transported, it must be converted into some neutral salt or changed into concentrated acid of 95 per cent strength, which can be shipped in aluminum tank cars. The concentration is accomplished by means of sulphuric acid, which has a greater affinity for the water in the weak nitric acid, thus absorbing it, leaving the nitric acid in concentrated form.

The neutral salt, generally produced from the weak acid, is calcium nitrate, also known as nitrate of lime or Norway saltpeter, because it is the main product of the large nitrate plants in Norway. The calcium nitrate $Ca(NO_3)_2$, is thus produced by treating ordinary limestone with the weak acid, the reaction being as follows:

$$Ca\,CO_3+2\,HNO_3=Ca(NO_3)_2+H_2O+CO_2$$

The resulting solution is evaporated by the waste heat from the steam boilers before mentioned, and the product is then ready for the market.

This calcium nitrate contains 13 per cent of fixed nitrogen, and is, like Chile saltpeter, an excellent fertilizer, although somewhat hygroscopic. It is, as stated, the main product of the large Rjukan nitrate plants in Norway, which have an annual productive capacity of about 200,000 tons of nitrate, equivalent to about 26,000 tons of fixed nitrogen. Over 300,000 electrical horsepower are used for this, generated in magnificent high-head water power plants. The power requirements with this process are thus about 12 h.p. years per ton nitrogen fixed, and from this high rate of consumption it follows that the price of the power must be very low in order to make the process an economic success.

The majority of the furnaces used at Rjukan are of the Birkeland-Eyde type, the latest designs having a capacity of 4000-5000 h.p. each. There are also some Schoenherr furnaces of 1000 h.p. capacity each. Numerous other types of furnaces have been proposed and patented, but none except the above-mentioned types have come into any general use. With the exception of the above-mentioned large plants in Norway, the process has had a very limited use. One plant of moderate size has been in operation in France, and the activities in this country have so far been confined to two small installations, one in the West and one in the South.

(To be continued)

Stress Distribution in Electric Railway Motor Pinions as Determined by the Photo-elastic Method

By Paul Heymans, Cambridge, Mass.
and A. L. Kimball, Jr., Research Laboratory, General Electric Company

This article embodies some results of a general scientific study undertaken for the development of superior electric-railway motor pinions. The particular portion of the work described was performed at the Massachusetts Institute of Technology, using the General Electric Company's apparatus for stress determination in transparent models by the photo-elastic method. Some of the supplementary mechanical tests were made at Schenectady, and throughout the work close contact was maintained with the Railway Motor Department and the Research Laboratory at Schenectady. A brief description and discussion of the photo-elastic method is given in the first part. The stress distribution in, and the causes of ruptures of, given types of gear pinions used in electric-railway motors, as investigated by the photo-elastic method, are afterward reported upon and discussed. This article was presented as a paper at the annual meeting, New York, December 4 to 7, 1922, of the American Society of Mechanical Engineers.

I. DESCRIPTION OF THE METHOD

How to Define the State of Stress at any Point of a Solid Body

The state of stress at any point in a solid body is determined when the traction across every plane through the point is known. There exist at any point three orthogonal planes across which the traction is purely normal and which are called the planes of principal stress. The normal tractions across those planes are called the principal stresses. The state of stress at any point is completely determined by the direction and the magnitude of the principal stresses at the point under consideration. The principal stresses, given in direction and in magnitude, express in the most general and complete way the elastic state at any given point. The bending moment, the shearing forces, etc., are readily deduced from the direction and the magnitude of the principal stresses. Furthermore, one of the principal stresses always expresses the maximum stress.

2. The notion of principal stress may be illustrated as follows:

3. Consider a spherical element in a solid body. External applied loads will deform this spherical element into an ellipsoidal element (Fig. 1). The axes of this ellipsoid will correspond in direction and in magnitude to the direction and the magnitude of the principal stresses.

4. The orientation and the form of the ellipsoid, and therefore the direction and the magnitude of the principal stresses, will define the state of stress at the point under consideration.

5. The axes of the ellipsoid represent the largest and the smallest deformation at the point under examination. Correspondingly, the principal stresses give the direction and the magnitude of the maximum and the minimum stress.

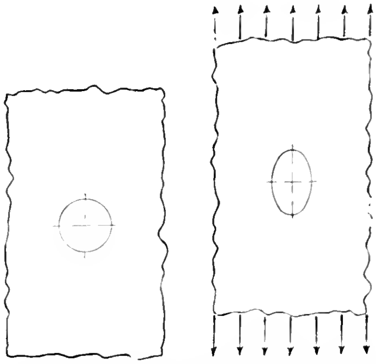

Fig. 1. Ellipsoidal Element Resulting from Subjecting a Spherical Element to Stress

6. If the three principal stresses vary from point to point in the structure, the problem to be dealt with is a three-dimensional elastic one. If one of the three principal stresses vanishes throughout, it is a two-dimensional elastic or plane-stress problem.

7. Corresponding to the three- and two-dimensional elastic-stress problems there are also the three- and two-dimensional elastic-strain problems, when the deformations corresponding to the principal stresses are considered.[1]

8. A great number of structural problems (bridge, ship, airplane, plate, dam, etc., construction) are, or their stress analysis may be reduced to, two-dimensional elastic problems.

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[1] A complete theory of stress and strain may be found in the "Treatise on the Mathematical Theory of Elasticity," by A. E. H. Love, 3d ed., chapters i-iv.

The Photo-elastic Method of Stress Determination

9. As set forth in Par. 1, the state of stress at any point is most completely defined by the direction and the magnitude of the principal stresses. These are, therefore, the elements which we wish to determine for a complete analysis

Fig. 6. Frame for Comparison Member Designed by E. G. Coker and A. L. Kimball, Jr.

10. The photo-elastic method solves the two-dimensional elastic problems. It primarily takes advantage of the double refracting properties shown by isotropic transparent substances when put under stress. The stresses in the structure may therefore be determined from models made of a homogeneous transparent material, and ordinarily on a reduced scale. The stresses in a steel, cement, or any other structure, homogeneous throughout and obeying Hooke's law of linear proportionality between stress and strain, may be readily deduced from the values obtained by the analysis of the corresponding transparent model for the case of two-dimensional elastic problems.

11. If plane polarized light is passed through a stressed specimen of celluloid and afterward through a second nicol prism whose principal section is parallel to the plane of polarization of the original beam of light, only the points where the principal stresses are respectively parallel and perpendicular to the principal sections of the crossed nicols remain dark. This result makes it possible to determine the directions of the principal stresses at any given point. Morever, this information is needed for the measurements which will be described later.

12. If now circularly polarized light be passed through the specimen, by interference of the two component rays, which in the double-refracting specimen have suffered a relative retardation at each point proportional to the difference in magnitude of the two principal stresses, a colored image is obtained. (Figs. 2, 3, 4 and 5.)*

13. By a comparison method, based upon the interposition in the proper direction of a comparison member of constant cross-section, put under uniform tension in a suitable frame (Fig. 6), the value of the difference of the principal stresses at any given point may be read on the dynamometer of the frame.

14. Now, in the two-dimensional elastic problems the transverse deformation, i.e., the deformation along a normal to the plane of the two principal stresses, is proportional to the sum of those two stresses. By means of a lateral extensometer (Fig. 7), we measure this transverse deformation.

15. From the values of the differences and the sums of the principal stresses, the separate values of each of them are computed, thus determining completely the state of stress.

16. A question naturally arising is whether the results obtained on a transparent body such as celluloid hold for structural materials.

17. It is shown by the general discussion of the equations of elastic equilibrium that in the case of strain or plane stress in an isotropic body obeying Hooke's law of linear proportionality between stress and strain, the stress distribution is independent of the moduli of elasticity and consequently of the material of which the body is made. Thus the stress distribution experimentally determined in the case of a celluloid body is the same as it is when the body is made of any other isotropic substances such as iron, steel, etc., obeying Hooke's law, in distribution,

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*See Frontispiece of this issue of the Review.

direction, and magnitude.[1] Moreover these conclusions derived from the general theory of elasticity have been checked by experiment.[2]

18. The photo-elastic method can be applied to the great majority of structural problems, not only in taking the place of mathematical computation, but particularly in solving those structural problems where mathematics becomes too involved to be of help. Moreover it has the great advantage of giving the maximum stress at each point throughout the whole structure, and it therefore offers an effective means of increasing safety and reducing superfluous material.

II. A STUDY OF THE STRESS DISTRIBUTION IN GEAR PINIONS

19. When accidents occur with gear wheels, besides the metallurgical question, three possible causes of failure suggest themselves:

a. The gear wheel may not have been properly designed.

b. It may have failed under an excessive load.

c. When the pinion was shrunk hot or forced on to a tapered shaft, an excessive inside radial pressure may have been set up.

20. It is easy to see that the ordinary methods of resistance calculations of gear wheels, based on considering the tooth as a cantilever loaded at its end, would not be expected to give reliable and complete information as to stress distribution, not even for the root section of the tooth which is under consideration.

21. Indeed, the shape of the tooth, the curvature at the root, the ratio of the diameter of the pinion bore to the root and outside diameter, the permanent stresses introduced by the placing of the pinion on the shaft, etc., all affect the stress distribution and the maximum stress. Photo-elastic analysis shows that these factors affect the stresses considerably more than would be expected from present methods of estimating. For standardized pinions the correction coefficients can only partially take account of these factors. For special pinions or for pinions of which more efficient running is required a photo-elastic analysis seems to be the best if not the only effective way to determine the stress distribution and to locate the maximum stress.

22. A detailed analysis of the stress distribution determined for different gear pinions and under different loading conditions is given below.

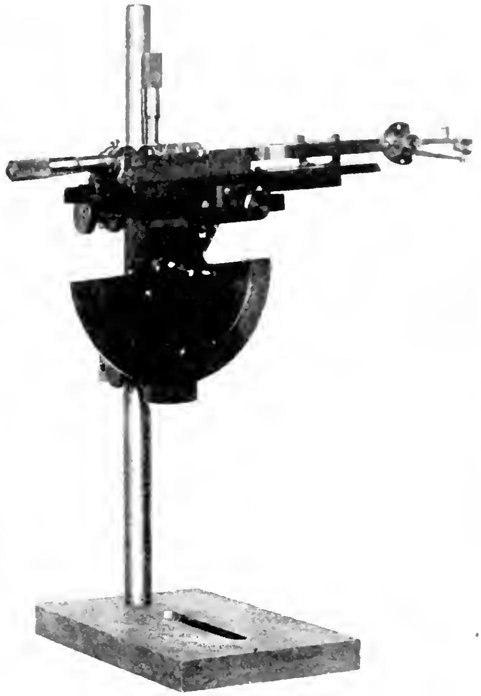

Fig. 7. Lateral Extensometer Designed by P. Heymans

23. The authors wish first to call attention to certain interesting points brought out by photo-elastic analysis, which have been checked by tests carried out on steel sections. These are particularly interesting because they are unexpected.

24. Besides the stress distribution in the different sections of the pinions represented by Fig. 8, the photo-elastic analysis has given as maximum stress under normal inside radial pressure and normal torque:

80,000 lb. per sq. in. for tooth form *A*
70,350 lb. per sq. in. for tooth form *B*
60,900 lb. per sq. in. for tooth form *C*.

Moreover the 12-tooth pinion shows, besides a smaller maximum stress, a better stress distribution.

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[1] Except, however, if the body is multiply connected and the resultant applied forces do not vanish separately over each boundary. In this particular case the correction coefficients for passing from one isotropic substance to another may be experimentally determined. ("On Stresses in Multiply-connected Plates," by L. N. G. Filon, British Assn. Report, 1921.)

[2] "Photo-elastic Measurements of the Stress Distribution in Tension Members Used in the Testing of Materials," by E. G. Coker, Excerpt Proc. Inst. C. E. (London),—vol. ccvii, part II, p. 8.

"Photo-elastic and Strain Measurements of the Effects of Circular Holes on the Distribution of Stress in Tension Members," by E. G. Coker, Trans. Inst. Engrs. & Shipbuilders in Scotland, vol. lxiii, part I, p. 33.

"La Photo-elasticimétrie, ses principes, ses méthodes et ses applications," by Paul Heymans. Bull. Soc. Belge Ing. et Ind., Aug., 1921, pp. 147-154, 165-167, 189-199.

25. For steel pinions the maximum stress attained under normal conditions, although high, appears not to be excessive. *Tooth C appeared to be a better design* under normal conditions.

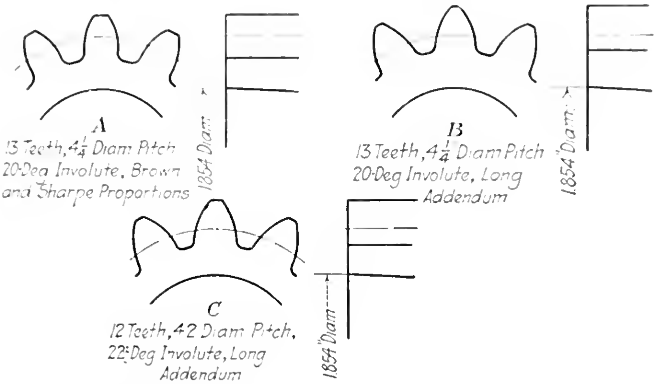

Fig. 8. Tooth Forms of Pinions Subjected to Photo-Elastic Analysis

Fig. 9. Steel Rings Ruptured by Being Forced onto a Tapered Plug

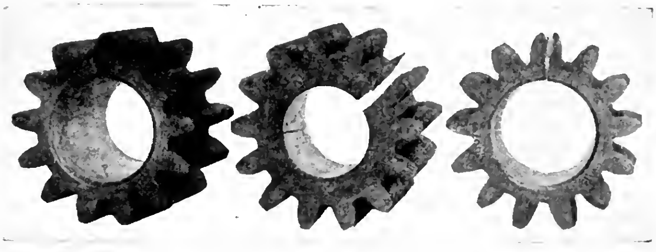

Fig. 10. Steel Pinions Ruptured by Being Forced onto a Tapered Plug

26. The stresses due to shrinking or forcing the pinion on the shaft can only be estimated. The pinion may be assumed to be a plain circular ring, for which case the stresses may be mathematically computed. The stress at any point of the ring as well as the maximum stress in the ring depends upon the lengths of the inside and outside radii. The opinion generally expressed is that for the case of the pinion the maximum stress will be intermediate between the maximum values obtained for rings of which the outside diameters are respectively equal to the root diameter of the tooth and to the outside diameter of the pinion, the inside bore being the same.

27. Photo-elastic analysis shows that *the gear pinion is even weaker than the plain circular ring whose outside diameter is equal to the root diameter of the tooth.* The change of external profile, due to the presence of the teeth, although requiring an addition of material, weakens the structure.

28. Figs. 9 and 10 show the steel specimens after having been tested by forcing a tapered plug into the bore; and Table I gives the rupture load applied to the tapered arbor forced into the bore for the different specimens. These confirm the photo-elastic results.

29. Previous to the photo-elastic investigation of the stresses due to radial inside pressure in pinion sections, fracture due to pure radial inside pressure would have been expected to occur through the minimum radial cross-section.

30. From Fig. 2,* representing the color image obtained in the photo-elastic analysis, it appears that *the regions under the teeth are under higher stress* and that the points at the inside boundary right under the teeth are points of maximum stress.

31. Fig. 10 gives the fracture obtained on steel sections. Two of the sections show fractures right through the thickest layer of material, while all of them started at points where the photo-elastic analysis had revealed maximum stress. The unevenness of the material must account for the deviation of the fracture in one of the cases.

32. Can any statement be made as to the causes of the failure by inspection of the shape of the fracture? In the case in which the authors were interested, the photo-elastic analysis determined the best design. As before said, either the placing of the pinion on the shaft, if carelessly done, for instance by pounding the pinion heavily on the tapered

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* See Frontispiece of this issue of the REVIEW.

shaft, or excessive torque and blows due to sudden meshing or the taking on of a heavy load, will set up dangerous stresses.

TABLE I

RUPTURE LOAD ON ARBOR FORCED INTO SPECIMENS TESTED

	Inside Diam., In.	Outside Diam., In.	Root Diam., In.	Rupture Load, Lb.
Ring	1.854	3.5	....	85,000
Ring	1.854	2.5	....	51,000
Pinion	1.854	3.5	2.5	47,000

33. The authors' photo-elastic analysis has shown that *the sections of dangerous stresses are different for different values of inside radial pressure and applied torque load.*

Fig. 11. Fatigue Failures of Teeth Produced by Experiment (without Radial Pressure in Bore)

34. The fracture shown in Fig. 11 is of an *open* V-shape. Photo-elastic analysis shows that *the higher the inside radial pressure becomes*, for a given torque load, *the sharper becomes the V-shape of the section of dangerous stresses.* (Fig. 12.) If the fracture is due to too high a torque load, the angle of the V will approach 180 deg. Tests on steel sections have been made with a specially built impact machine.

35. Without inside radial pressure the fracture obtained is a straight line through the root section of the tooth. With increasing pressures the V-shaped fracture becomes sharper. For an inside radial pressure exceeding the elastic limit, however, the observation does not hold. The reason for this departure from what the photo-elastic method had predicted is to be found in the fact that beyond the elastic limit the stress-and-strain relation no longer follows Hooke's law. [illegible] stresses set up in the steel pinio [illegible] shrinking process no longer correspo [illegible] those set up in the celluloid model.

36. While the flat shape of the break in Fig. 11 is one limiting case (torque without radial shrinking pressure), Fig. 10 may be considered as the other limiting case (radial shrinking pressure without torque), showing a V-shaped fracture for which the angle of the V has become equal to zero.

37. It may be concluded, then, that the inspection of the fracture may be a means of determining the cause of the failure. In this way, possibly, the responsibility may be established between builder and customer as regards pinion mounting.

Fig. 12. Fatigue Failures of Teeth Produced by Experiment (with Heavy Radial Pressure in Bore

The Detailed Stress Analysis

38. *External Forces Applied to the Pinion When in Service.* The pinion is shrunk onto the shaft after having been bored so as to fit the shaft at a temperature of 160 deg. F. above normal room temperature.

39. In normal working conditions, the torque load to which the pinion is subjected corresponds to a tractive force of 500 lb. per inch of face of the tooth, tangent in direction to the pitch circle. The whole torque is supposed to be transmitted by a single contact.

40. Calling respectively $\widehat{rr}$ and $\widehat{\theta\theta}$ the radial and the tangential principal stress in a circular ring, of which the outside diameter equals the root diameter of the teeth, the inside bore being the same as the pinion bore, $(\widehat{rr}-\widehat{\theta\theta}) = 28{,}800$ lb. per sq. in. for $\Delta t = 160$ deg. F. This value of $(\widehat{rr}-\widehat{\theta\theta})$ is the stress value of the color bands obtained in polarized light (isochromatic bands), and will therefore be used

in the stress analysis of the celluloid model to secure the right expansion pressure before the torque is applied. For radial pressures higher than this normal shrinking pressure, the same characteristic of the $(rr-\theta\theta)$ value will be used.

41. The tangential tractive force is applied at varying distances from the root of the tooth, depending upon the point of contact. The most unfavorable conditions arise when this force is applied at the top of a single tooth. Moreover the starting torque load being higher than that realized under normal running conditions, the applied tractive force was brought up from 500 lb. to 1500 lb. per inch of face.

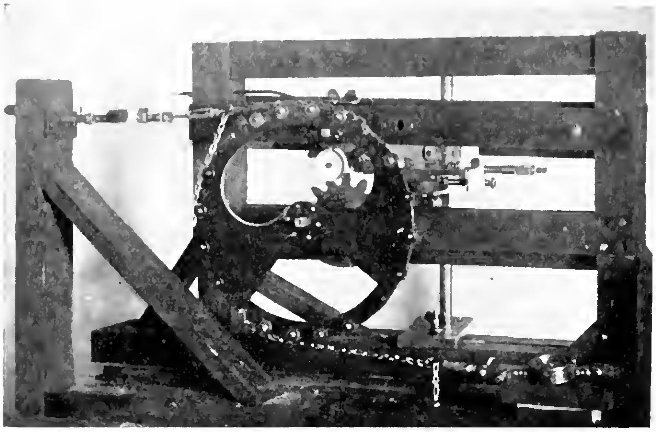

Fig. 13. Frame Used for Applying Loads to Celluloid Models of Pinions

42. Let us for convenience call:

a. The *normal* inside pressure, the value of 28,800 lb. per sq. in. for $(\widehat{rr}-\widehat{\theta\theta})$, corresponding to a shrinking pressure due to a temperature variation of 160 deg. F.

b. The *maximum* torque, the torque corresponding to a tractive load F of 1500 lb. applied normally to the contour of the tooth (condition of contact) at the top of one pinion tooth.

c. The *normal* torque, the torque corresponding to a tractive load F of 500 lb. applied under the same conditions as above.

d. Increased inside pressures, the values of $(\widehat{rr}-\widehat{\theta\theta})$ exceeding the normal inside pressure, as defined above.

43. *The Photo-Elastic Analysis.* Fig. 13 represents the frame used for the loading of the models. A tapered expansion ring is used to produce the radial inside pressure. The torque is measured by properly mounted dynamometers.

44. The first sets of measurements were made under normal inside pressure and maximum torque load. Fig. 14 represents the lines of principal stress, deduced from the isoclinic bands. The tangents to these lines represent at each point the directions of the principal stresses.

45. Fig. 2* gives the colored image when the normal inside pressure alone is applied, whereas Figs. 3* and 4* give the image obtained when both the normal inside pressure and the maximum torque are applied. An optical measurement on the image shown in Fig. 2* allows one to adjust properly the amount of inside pressure before the torque is applied.

46. The determination of the values of the difference $(p-q)$ of the principal stresses is made on the image shown in Fig. 4.* One of the two principal stresses vanishes at a boundary where no external forces are applied. In this case the optical measurements of the values of $(p-q)$ give directly the values of the tangential stress.

47. Inside of the body the optical measurements are supplemented by measuring the transverse change of thickness, which gives the values of the sum $(p+q)$ of the principal stresses.

TABLE II

VALUES OF THE PRINCIPAL STRESSES ACROSS THE MINIMUM CROSS-SECTION OF THE LOADED TOOTH

Tenths of Distance *AB* (Fig. 15) Measured from *A*	p Lb. per Sq. In.	q Lb. per Sq. In.
0	0	72,600
0.1	13,850	57,300
0.2	10,450	49,000
0.3	3,710	41,700
0.4	—10,620	25,800
0.5	—20,300	18,700
0.6	—29,000	11,900
0.7	—40,000	9,000
0.8	—51,900	---------
0.9	—65,700	5,320
B	—80,000	0

48. From the values of the principal stresses at a given point it is easy to obtain the stress on a section in any given direction at that point. Moreover, as said before, the two principal stresses represent respectively the maximum and the minimum stress. Thus the larger of the principal stresses will always

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* See Frontispiece of this issue of the REVIEW.

give at each point the maximum stress in direction and magnitude.

49. At the edges where one of the principal stresses has vanished the values of $(p-q)$ and $(p+q)$ must correspond, i.e., the optical determination of $(p-q)$ and the determination of $(p+q)$ must check.

50. Also if we know the total force acting normally to a given section, the graphical integral of the curve, obtained by plotting the resultant stresses acting normally to this section, must correspond to the total force. In the case of the pinions the data for such a check are not available.

51. Table II gives the values of the principal stresses through the minimum cross-section of the pinion tooth, to which the load is applied. The results given in this table have been plotted in Fig. 15. At each point where measurements have been made the two principal stresses have been plotted in direction and in magnitude, the arrows serving to distinguish between tension and compression. At the points A and B, $(p-q)$ and $(p+q)$ must check: they differ for A by 0.9 per cent and for B by 0.8 per cent.

52. The maximum tension occurs at A and is equal to 72,600 lb. per sq. in. The maximum compression occurs at B and is equal to 80,000 lb. per sq. in. This difference between the absolute values of these stresses is of course due to the pressure on the inside of the pinion, which affects the tension and the compression stresses differently.

53. Figs. 16 and 17 give the values of the tangential stresses along the edge of the tooth on which the load is applied. The numerical results of Table III have been plotted in Fig. 16, this table giving the tangential stresses at the tension side. Also the numerical results of

TABLE III

VALUES OF THE TANGENTIAL STRESS AT THE BOUNDARY OF THE LOADED TOOTH—TENSION SIDE

No. of Point in Fig. 16	q Lb. per Sq. In.	
1	41,000	
2	54,100	
3(A)	72,300	72,750[1]
4	73,200	
5	64,800	
6	57,600	
7	54,100	
8	41,000	
9	....	

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[1] Value obtained by taking ½ $[(p+q)+(p-q)]$, the other values being $(p-q)$ measurements.

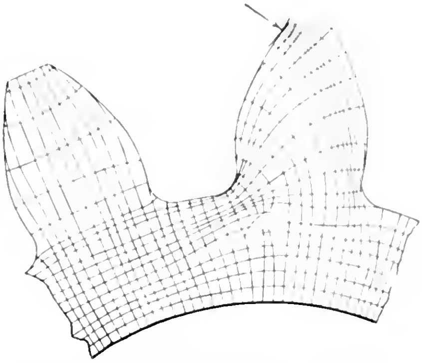

Fig. 14. Lines of Principal Stress Determined by Polarized Light—Normal Inside Pressure and Maximum Torque Load

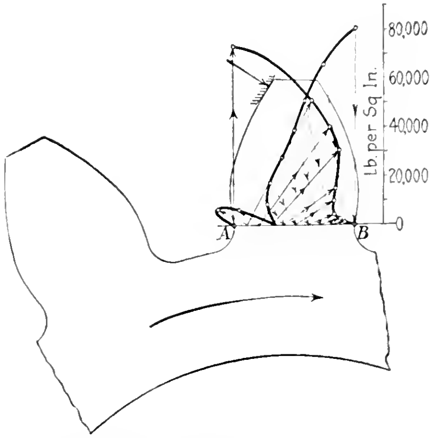

Fig. 15. Curves showing the Two Principal Stresses in Direction and Magnitude for Points along the Section AB

TABLE IV

VALUES OF THE TANGENTIAL STRESS AT THE BOUNDARY OF THE LOADED TOOTH—COMPRESSION SIDE

No. of Point in Fig. 17	p Lb. per Sq. In.	
1	20,500	
2	41,000	
3(B)	79,500	80,000[1]
4	80,000	
5	82,200	
6	60,000	
7	29,000	
8	0	

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[1] Value obtained by taking ½ $[(p+q)+(p-q)]$, the other values being $(p-q)$ measurements.

Table IV have been plotted in Fig. 17, this table giving these stresses on the compression side. Since no external load is applied at this side, the optical measurements give the values of the tangential stresses up to the top of the tooth.

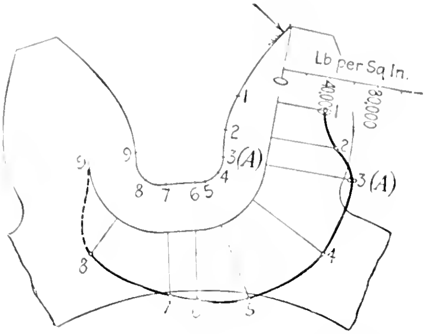

Fig. 16. Tangential Stress at Tension Side—Normal Inside Pressure and Maximum Torque

54. Table V and Fig. 18 give the numerical and plotted values of the stress difference $(\widehat{rr}-\widehat{\theta\theta})$ along the inside boundary of the pinion, the normal inside pressure and the torque load being applied. A circular ring to which a uniform inside pressure is applied will show concentric isochromatic bands. The deflections of those bands (Fig. 2)* in the case of the pinion show the disturbance due to the presence of the teeth.

55. When the maximum torque is applied, the values obtained for $(\widehat{rr}-\widehat{\theta\theta})$ give the curve of Fig. 18. The colored images as well as the diagrams show that the load applied at the top of one tooth extends its influence as far as the inside boundary of the pinion. The combination of the inside uniform pressure, already disturbed by an irregular outside boundary, with irregularly distributed stresses—tensions in certain parts and compressions in others—due to the torque load, do not of course give a resultant stress distribution which shows any symmetry with respect to the point of contact. The upper pinion being the driving pinion, it may be seen on the colored image (Fig. 3)* that the stresses vanish rather rapidly in the withdrawing part, but that the penetration extends much farther into the approaching part.

56. It may also be interesting to point out that there is a zone of zero stress inside of the pinion under the root of the tooth when the torque load is applied. This is shown on the diagram of the lines of principal stress (Fig. 14) by the converging of the lines of principal stress, as several lines of principal stress can only intersect where the principal stresses vanish.

57. The question of engineering interest was to find the relative influence of the factors which affect the maximum stress, and the authors therefore varied the values of:

a. The inside normal pressure

b. The torque load.

TABLE V

VALUES OF $(\widehat{rr}-\widehat{\theta\theta})$ ALONG THE BOUNDARY OF THE BORE

No. of Point in Fig. 18	$(\widehat{rr}-\widehat{\theta\theta})$ Lb. per Sq. In.
1	36,600
2	54,100
3	36,600
4	18,100
5	41,000
6	61,500
7	43,500
8	38,700

58. The values of $(\widehat{rr}-\widehat{\theta\theta})$ along the inside boundary when the maximum torque load is applied are given in Table VI and have been plotted in Fig. 19 for the case of reduced inside pressure. The colored image did not show noticeable variation across the minimum cross-section AB and along the outside edges of the main tooth. The influence of the inside pressure on the above-mentioned limit does not affect materially the regions of maximum stress, due in this case to the torque load.

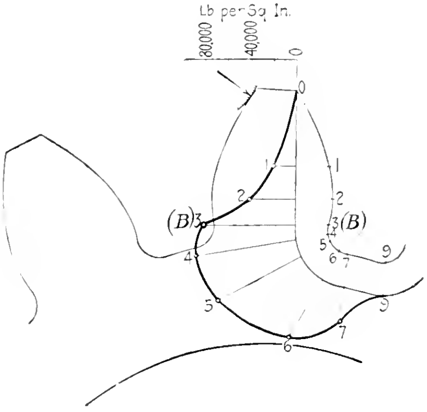

Fig. 17. Tangential Stress at Compression Side—Normal Inside Pressure and Maximum Torque

59. Fig. 5* shows the image obtained for normal pressure and reduced torque. Having applied 0.7 of the maximum torque value, the

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* See Frontispiece of this issue of the REVIEW.

stresses showed a general reduction in the region of high stress. The values of the tangential stresses along the tension side of the boundary of the main tooth are given in Table VII and are plotted in Fig. 20. This should be compared with the same diagram (Fig. 16) for the case where the full load is applied. The maximum tension has dropped from 73,200 lb. per sq. in. (Table II) to 57,700 lb. per sq. in. (Table VII); i.e., it has been reduced to 0.8 of its previous value. The fact that it has dropped only to 0.8, whereas the torque was reduced to 0.7, is explained by the permanent stress due to the inside radial pressure which had been maintained at its previous value. A reduction of the torque load has as a result a reduction of the maximum stress. We shall see later that this is not always the case.

TABLE VI

VALUES OF $(\widehat{rr}-\widehat{\theta\theta})$ ALONG THE BOUNDARY OF THE BORE

(Maximum torque — reduced radial pressure)

No. of Point in Fig. 19	$(\widehat{rr}-\widehat{\theta\theta})$ Lb. per Sq. In.
1	37,600
2	36,600
3	20,500
4	14,550
5	20,500
6	36,600
7	54,100
8	54,100
9	41,000
10	20,500

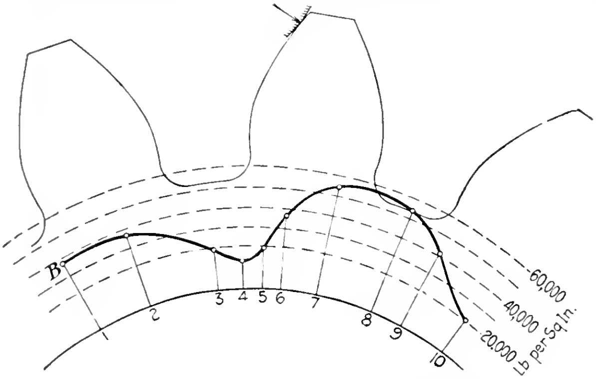

Fig. 19. Stresses along the Inside of Bore with Decreased Pressure (18,100 lb.) and Maximum Torque

60. When the inside radial pressure is increased in such proportion that without any torque being applied it produces stresses at the outside boundary of the gears of a magnitude approaching that due to the torque load, it will be this internal pressure which will have a preponderant influence.

61. Pinions have been examined with maximum values for $(\widehat{rr}-\widehat{\theta\theta})$ of 60,000 and 81,500 lb. per sq. in. at the inside boundary with the torque load at its normal value of 500 lb. tractive force per inch of face. The tractive force was afterward brought up to its maximum value of 1500 lb.

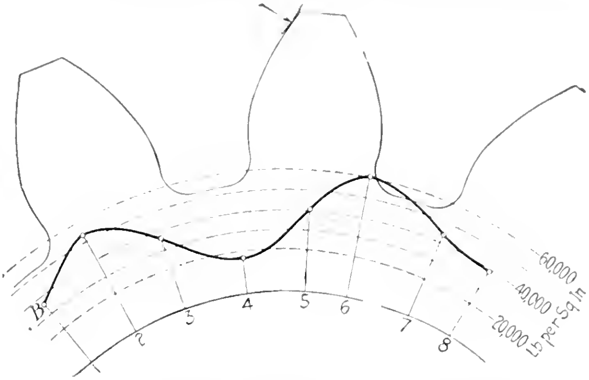

Fig. 18. Stresses along the Inside of Bore, with Normal Pressure (28,820 lb.) and Maximum Torque

TABLE VII

VALUES OF THE TANGENTIAL STRESS ALONG THE BOUNDARY OF THE LOADED TOOTH—TENSION SIDE

(Normal inside pressure — reduced torque)

No. of Point in Fig. 20	q Lb. per Sq. In.
1	39,700
2	51,500
3	58,500
4	57,700
5	56,600
6	51,500
7	38,000
8	19,500

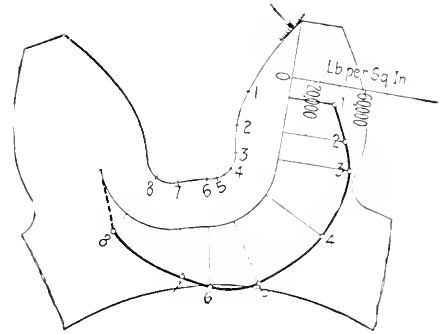

Fig. 20. Tangential Stress at Tension Side—Normal Inside Pressure and Reduced Torque

62. These tests showed that the torque load, when applied to the pinion subjected to those increased radial pressures, affects only the distribution of the stresses. It makes the high stresses extend over a larger area, but it does not increase materially the maximum stress. In these cases the dangerous section is no longer a straight section through the root of the tooth but it follows a V-shaped line, the lower point of which lies toward the inside bore. The sharpness of the angle of the V-shaped fracture at the base of the tooth appears to be due to an excess of radial shrinking pressure. In practice this excess is due to the pounding of the pinion onto the tapered shaft past its normal position.

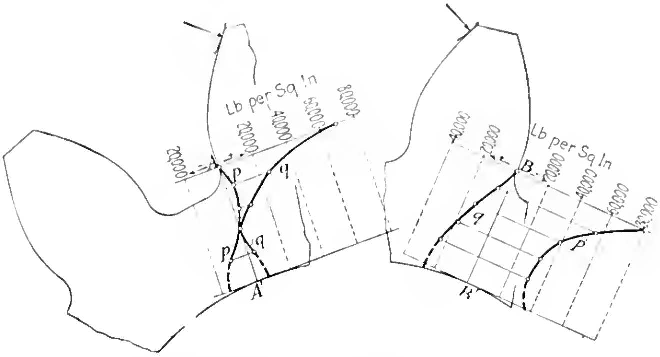

Fig. 21. Principal Stresses Across Radial Sections of Tooth—Normal Inside Pressure and Maximum Torque

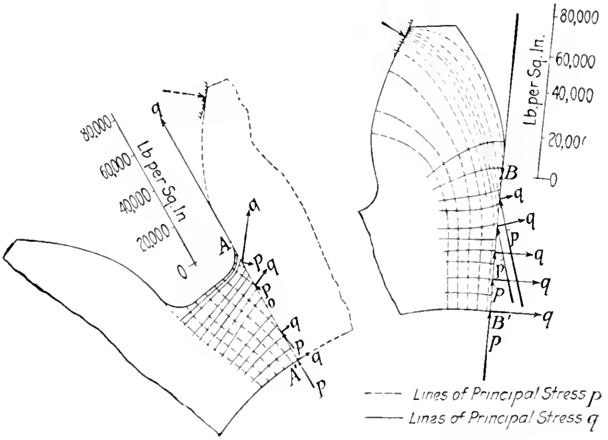

Fig. 22. Principal Stresses in Direction and Magnitude for Same Radial Sections as Those Shown in Fig. 21

63. In this connection a study was made of the stress distribution through two radial sections, passing respectively through the points A and B of the minimum cross-section of the main tooth, the points of maximum tension and compression.

64. The values of $(p-q)$ were deduced from the colored image of Fig. 1.* Extensometer measurements of $(p+q)$ were made. As before, the scales of both measurements were determined so that the stresses in the models should represent the stresses in the steel pinion.

65. The maximum torque and the normal inside pressure were applied. Table VIII and Figs. 21 and 22 give the values obtained. Fig. 21 gives the magnitude of the principal stresses along the two sections AA' and BB'. Fig. 22 gives a portion of the lines of principal stress taken from Fig. 14, and for the same sections AA' and BB' shows the two principal stresses plotted in direction and in magnitude.

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*See Frontispiece of this issue of the Review.

TABLE VIII

VALUES OF THE PRINCIPAL STRESSES ACROSS THE RADIAL SECTIONS PASSING RESPECTIVELY THROUGH THE POINTS *A* AND *B* OF THE MINIMUM CROSS-SECTION OF THE LOADED TOOTH

Cross-Section *BB'* Fig. 21; Distance in Inches from Point B'	p Lb. per Sq. In.	q Lb. per Sq. In.
0.410 (*B*)	79,900	0
0.334	55,800	6,000
0.256	39,000	15,200
0.179	32,600	18,400
0.102	27,100	23,500
Cross-Section *AA'* Fig. 21; Distance in Inches from Point A'		
0.410 (*A*)	0	69,350
0.334	4,350	25,400
0.256	2,700	10,300
0.179	0	0
0.102	−11,350	3,350

66. A good way to visualize the state of stress at a given point is to consider a rectangular element with its sides parallel to the two principal stress directions at that point. By considering such elements along the sections *AA'* and *BB'* (Fig. 22) from this viewpoint, one can form a mental picture of how the section is acted upon by the elastic forces.

67. It would require too much space to include in this article a full discussion and to make a complete report of the results summarized here. The authors trust that the material they have presented will stimulate those interested in this subject to further efforts in the development and use of the photo-elastic method.

68. It seems, finally, almost superfluous to call attention to the comparative ease with which such a stress problem as this can be handled by the photo-elastic method, whereas the use of ordinary engineering methods gives untrustworthy results and the exact mathematical solution based upon the theory of elasticity is impossible.

69. Acknowledgment is due to the Massachusetts Institute of Technology for permission to use in this article certain of the results included in the thesis submitted by Dr. Paul Heymans, University of Ghent, Belgium, as partial fulfillment of the requirements for the degree of Doctor of Science from the Institute.

Graphs for Calculation of Electron Emission from Tungsten, Thoriated Tungsten, Molybdenum and Tantalum

By Saul Dushman and Jessie W. Ewald

Research Laboratory, General Electric Company

In the operation of electron tubes such as are used in radio work and related fields, the most important problem is that regarding the maximum electron emission that may be obtained under any given conditions and the efficiency of this emission, that is, the relation between electron current and watts consumed in the cathode. The present article gives characteristic emission data and curves for four different metals, and also certain fundamental relations which should prove of assistance in the design of thermionic devices.—Editor.

1. Equation for Electron Emission

The generally accepted equation for electron emission as a function of the temperature is that first enunciated by O. W. Richardson. This equation is ordinarily expressed in the form

$$I = A_1\sqrt{T}\epsilon^{-b/T} \tag{1}$$

where I denotes the electron emission per unit area at the absolute temperature T,[*] and A_1 and b are constants for any one substance.

On the basis of the second law of thermodynamics and the assumption that evaporation of electrons from a metal can be considered as thermodynamically equivalent to the evaporation of a monatomic gas, S. Dushman[†] has recently derived the following relation for the electron emission as a function of the temperature.

$$I = AT^2\epsilon^{-b_0/T} \tag{2}$$

where A is a *universal constant*, and b_0 is the only specific constant whose value varies with the nature of the emitting surface.

If the electron emission I is expressed in *amperes per square centimeter*, the constant A has the value 60.2. Introducing this value into equation (2) and converting to ordinary logarithms, this equation may be written in a form which is more convenient for calculations, thus:

$$\log I = 1.7792 + 2\log T - \frac{b_0}{2.303\,T} \tag{3}$$

Fig. 1 shows a series of graphs of this equation in which log I is plotted as ordinate against b_0 at constant value of T. It will be observed that for two substances at the same value of T,

$$\log I' - \log I'' = \frac{b_0'' - b_0'}{2.303\,T} \tag{4}$$

where I', b_0' and I'', b_0'' refer to each substance respectively. Thus for *tungsten*, $b_0'' = 52{,}600$, while for thoriated tungsten $b_0' = 34{,}100$.[‡] According to equation (4) it follows that at $T = 1500$,

$$\log I' - \log I'' = 5.356$$

or

$$I'/I'' = 2.27 \times 10^5$$

That is, at $T = 1500$, the electron emission from thoriated tungsten is 227,000 times as great as that from pure tungsten.

The plots in Fig. 1 show that as the temperature increases, the value of ratio I'/I'' for any two substances decreases.

Table I gives values of b_0 for different substances as determined in this laboratory. These values are based on the temperature scale for tungsten as derived by A. G. Worthing and W. E. Forsythe.[§]

TABLE I

Substance	b_0
Tungsten	52,600
Molybdenum	50,000
Tantalum	46,500[‖]
Thorium	34,100
Calcium	26,000[‖]

2. Electron Emission from Tungsten, Thoriated Tungsten, Molybdenum and Tantalum

By means of these values of b_0, the values of log I and I at different values of T have been calculated according to equation (3). Table II gives the data for tungsten, thoriated tungsten, molybdenum and tantalum.

While this table gives values at 100 deg. intervals, values of the electron emission at intermediate temperatures may be obtained

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[*] Temperatures on this scale are also denoted as Deg. *K.* (Kelvin).

[†] A brief account of this derivation was published in Phys. Rev. *20*, 109 (1922). A much more comprehensive paper will appear shortly in the same Journal.

[‡] The experimental data on which these values are based will be discussed in a paper by S. Dushman, H. N. Rowe and C. A. Kidner, which will appear shortly in the Physical Review.

[§] Phys. Rev. *18*, 144 (1921).

[‖] These values are to be regarded as only first approximations to the real values.

with a satisfactory degree of accuracy by linear interpolation between the nearest tabulated values of log I.

Figs. 2 and 3 give the electron emission for tungsten, plotted on *semi-log paper* against the absolute temperature, while Fig. 4 gives similar data for thoriated tungsten. As the thorium evaporates rapidly at temperatures above 2300 deg. K and emission data below 1500 deg. K are of no practical interest, only the data for the interval 1500—2300 deg. K are given in the plot.

3. Energy Radiated from Tungsten and Efficiency of Emission

From the point of view of the engineer and designer of vacuum tubes it is of importance to know the electron emission per watt consumed in heating the cathode. According to A. G. Worthing and W. E. Forsythe* the energy radiated from tungsten at any temperature T is expressed by the relation

$$\log E = 3.680 \, (\log T - 3.30) - \frac{1040}{T} + 1.900 \quad (5)$$

where E = watts cm.^{2}, and ordinary logs are used.

Fig. 5 gives a graph of this relation on semi-log paper. From these data and the values of the electron emission, Fig. 6 has been plotted to show the *electron emission per watt* at any temperature, for tungsten, and Figs. 7 and 8 for the electron emission and also electron emission per watt at any given value of the watts per cm.^{2} The arrows indicate the scales to be used.

Assuming that the energy radiated from a thoriated tungsten surface is the same as that from pure tungsten, it is possible to calculate similar data for thoriated tungsten. Fig. 9 shows the electron emission per watt as function of T, and Fig. 10 shows the electron

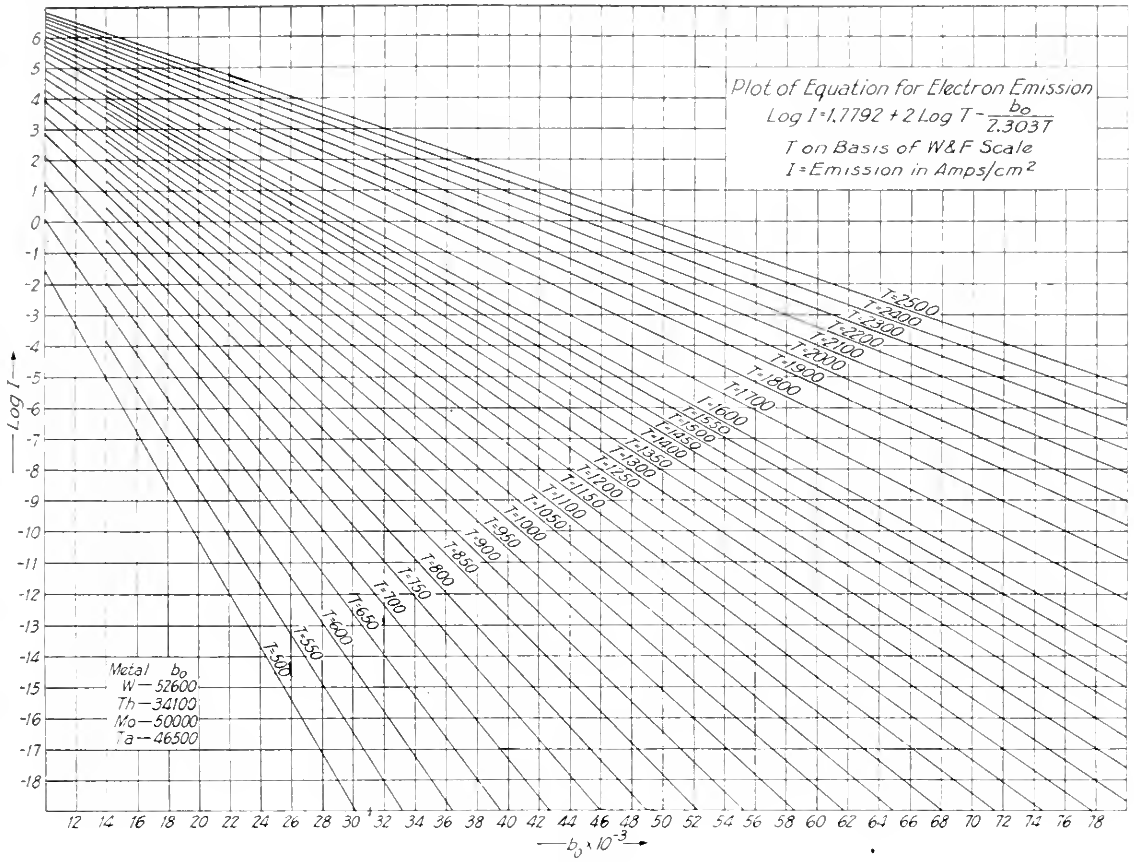

Fig. 1. Plot of Equation for Electron Emission

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* loc. cit.

TABLE II

ELECTRON EMISSION FROM TUNGSTEN, THORIATED TUNGSTEN, MOLYBDENUM, AND TANTALUM

T Deg. K	W		Th		Mo		Ta	
	log I	I	log I	I	log I	I	log I	I
800			$\overline{11}.08$	1.20×10^{-11}				
900			9.23	1.70×10^{-9}				
1000			$\bar{8}.96$	9.12×10^{-8}				
1100			$\bar{6}.40$	2.51×10^{-6}				
1200			$\bar{5}.60$	3.98×10^{-5}				
1300			$\bar{4}.60$	3.98×10^{-4}				
1400	9.76	5.75×10^{-9}	$\bar{3}.49$	3.09×10^{-3}	$\bar{8}.56$	3.63×10^{-8}	$\bar{7}.65$	4.47×10^{-7}
1500	$\bar{8}.90$	7.94×10^{-8}	$\bar{2}.26$	1.82×10^{-2}	$\bar{7}.66$	4.57×10^{-7}	$\bar{6}.67$	4.68×10^{-6}
1600	$\bar{7}.91$	8.13×10^{-7}	$\bar{2}.93$	8.51×10^{-2}	$\bar{6}.62$	4.17×10^{-6}	$\bar{5}.57$	3.72×10^{-5}
1700	$\bar{6}.80$	6.31×10^{-6}	1.53	3.39×10^{-1}	$\bar{5}.47$	2.95×10^{-5}	$\bar{4}.36$	2.29×10^{-4}
1800	$\bar{5}.60$	3.98×10^{-5}	0.06	1.15	$\bar{4}.23$	1.70×10^{-4}	$\bar{3}.08$	1.20×10^{-3}
1900	$\bar{4}.33$	2.14×10^{-4}	0.55	3.55	$\bar{4}.92$	8.32×10^{-4}	$\bar{3}.71$	5.13×10^{-3}
2000	$\bar{4}.96$	9.12×10^{-4}	0.98	9.55	$\bar{3}.52$	3.31×10^{-3}	$\bar{2}.29$	1.95×10^{-2}
2100	$\bar{3}.55$	3.55×10^{-3}	1.37	23.44	$\bar{2}.08$	1.20×10^{-2}	$\bar{2}.808$	6.43×10^{-2}
2200	$\bar{2}.07$	1.17×10^{-2}	1.73	53.70	$\bar{2}.59$	3.89×10^{-2}	$\bar{1}.285$	1.93×10^{-1}
2300	$\bar{2}.57$	3.71×10^{-2}	2.07	117.50	$\bar{1}.06$	1.15×10^{-1}	$\bar{1}.723$	5.28×10^{-1}
2400	$\bar{1}.023$	1.05×10^{-1}			$\bar{1}.49$	3.09×10^{-1}	0.126	1.34
2500	$\bar{1}.438$	2.74×10^{-1}			$\bar{1}.89$	7.76×10^{-1}	0.497	3.14
2600	$\bar{1}.825$	6.68×10^{-1}						
2700	0.183	1.52						
2800	0.518	3.30						

emission and emission per watt as a function of the watts per cm.^{2}

Table III gives values of E (watts/cm.^{2}), and I/E (electron emission per watt) at 100 degree intervals for tungsten and thoriated tungsten.

4. Lead Loss Correction

In practice the whole of the filament which is used as electron emitter is, of course, never at the maximum temperature. The temperature decreases more or less gradually to a very low value as the leads are approached. Consequently only a certain fraction of the total area of the filament is effective in emitting electrons. The magnitude of this fraction depends in a complicated manner upon the total length of the filament, the temperature, and the value of b_0.

Relations have been derived by Dr. I. Langmuir* for calculating the value of the factor f which connects the *observed electron emission* under any given conditions with the emission which would be obtained *if the whole of the filament were effective.* Thus, if i denotes the *observed emission* from a given

TABLE III

ENERGY RADIATED FROM TUNGSTEN

Also Efficiency of Electron Emission for Pure Tungsten and Thoriated Tungsten

T (Deg. K)	E watts/cm^2	I/E (amps./watt)	
		W	Th.
1000	0.570		1.59×10^{-7}
1100	1.008		2.51×10^{-6}
1200	1.663		2.40×10^{-5}
1300	2.600		1.51×10^{-4}
1400	3.899	1.48×10^{-9}	7.94×10^{-4}
1500	5.632	1.41×10^{-8}	3.24×10^{-3}
1600	7.889	1.02×10^{-7}	1.07×10^{-2}
1700	10.77	5.89×10^{-7}	3.16×10^{-2}
1800	14.39	2.75×10^{-6}	7.94×10^{-2}
1900	18.82	1.15×10^{-5}	1.91×10^{-1}
2000	24.19	3.80×10^{-5}	3.98×10^{-1}
2100	30.66	1.15×10^{-4}	7.58×10^{-1}
2200	38.30	3.09×10^{-4}	1.41
2300	47.30	7.94×10^{-4}	2.51
2400	57.77	1.82×10^{-3}	
2500	69.82	3.89×10^{-3}	
2600	83.77	7.94×10^{-3}	
2700	99.74	1.51×10^{-2}	
2800	117.7	2.82×10^{-2}	

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* I. Langmuir, Trans. Far. Society *17*, Part 3, 1921.

Formulæ for the end-loss correction have also been derived by A. G. Worthing (Journ. Franklin Inst. *194*, 597 (1922). But these relations apparently do not agree as well with actual data as Langmuir's relations.

filament and S denotes the total area of the filament, the electron emission per unit area after taking into account the lead loss correction is

$$I = \frac{if}{S} \tag{6}$$

The factor f is calculated by means of the relation

$$f = \frac{V + \Delta V}{V + \Delta V - \Delta V_H} \tag{7}$$

where V = voltage drop along filament
$\Delta V = 0.00026\ (T - 400)$
and ΔV_H is a function of b_0 and T.

Fig. 11 gives plots of ΔV_H and ΔV as functions of T for different values of b_0.

$V + \Delta V$ corresponds to the corrected voltage drop along the filament and from this the corrected watts per cm² of the filament may be derived. In the case of tungsten and thoriated tungsten filaments which are not too short, the temperatures may be calculated fairly accurately from the values of the corrected watts/cm² by means of equation (5) or Table III.

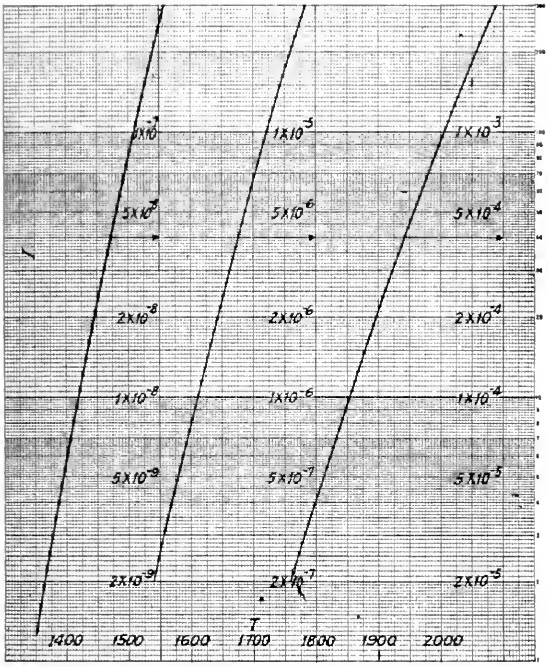

Fig. 2. Electron Emission from Tungsten at Lower Temperatures

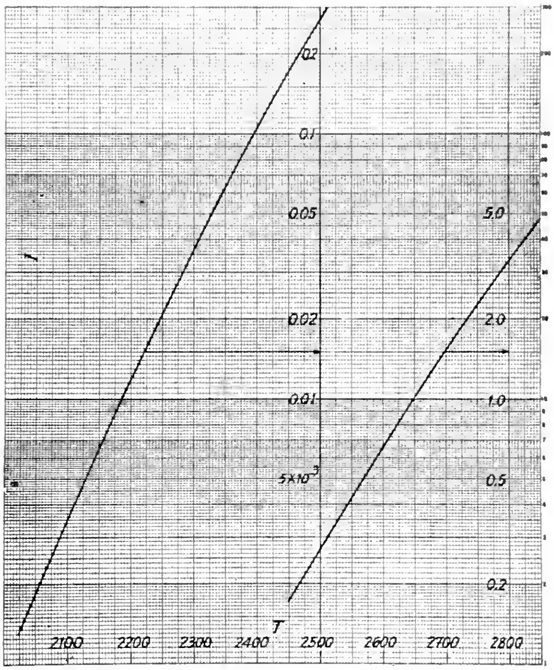

Fig. 3. Electron Emission from Tungsten at Higher Temperatures

5. Correction for "Schottky Effect"

As equation (2) was derived on the assumption that the electric field strength at the cathode is zero, while in actual practice a definite anode potential is used, it is necessary to reduce the values of the observed emission to those which would correspond to the conditions postulated in the theoretical derivation.

It was shown by W. Schottky* that if i_0 denotes the electron emission at zero field strength, and i_V denotes the observed emission at an anode voltage V, then

$$i_V = i_0 \epsilon^{\frac{4.39\sqrt{kV}}{T}} \tag{8}$$

where k is a constant whose value depends upon the relative geometrical arrangement of anode and cathode. Thus for a filament of radius r (in cm.) in the axis of a cylindrical anode of radius R,

$$k = \frac{1}{2.303\ r \log R/r} \tag{9}$$

In most cases, the value of k can be obtained much more accurately by measuring the emission (at constant temperature of the cathode) for different values of V.

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* Physikal. Zs. *15*, 872 (1914).

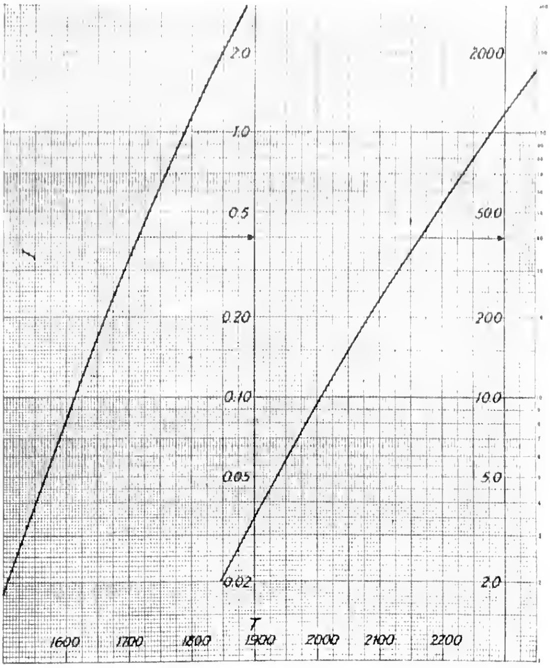


Fig. 4. Electron Emission from Thoriated Tungsten

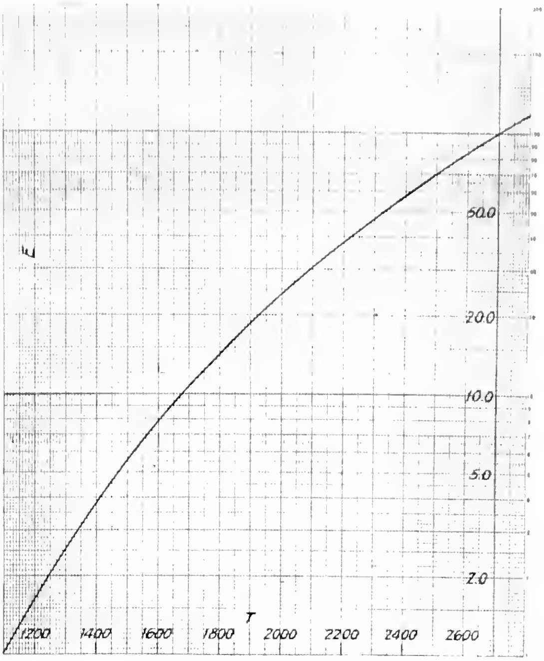


Fig. 5. Energy Radiated from Tungsten

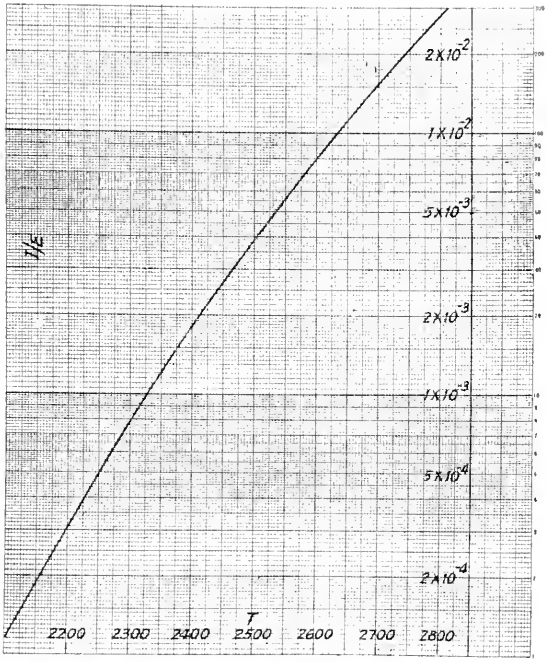


Fig. 6. Electron Emission per Watt for Tungsten as Function of Temperature

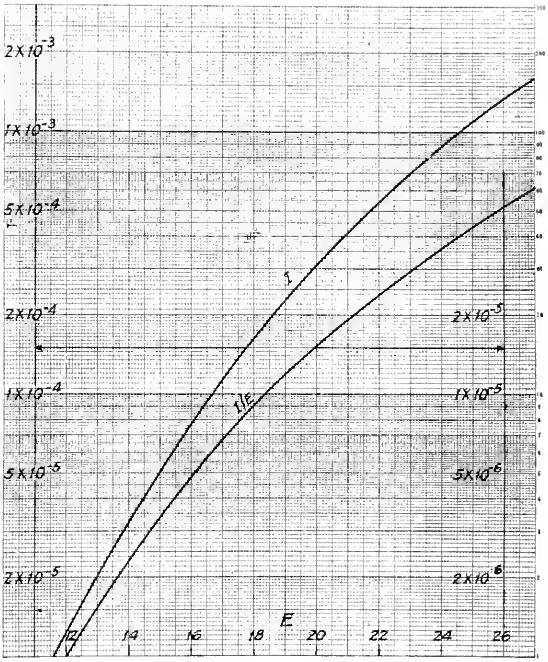


Fig. 7. Efficiency of Emission for Tungsten as Function of Watts per cm.

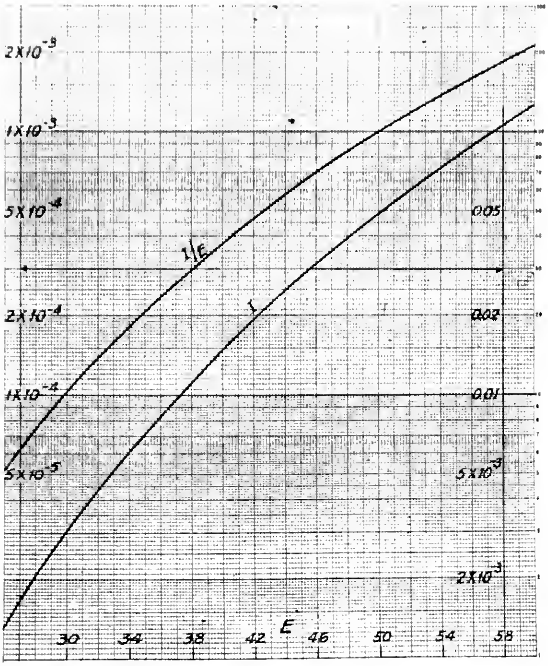


Fig. 8. Same as Fig. 7 for Larger Values of Watts per cm².

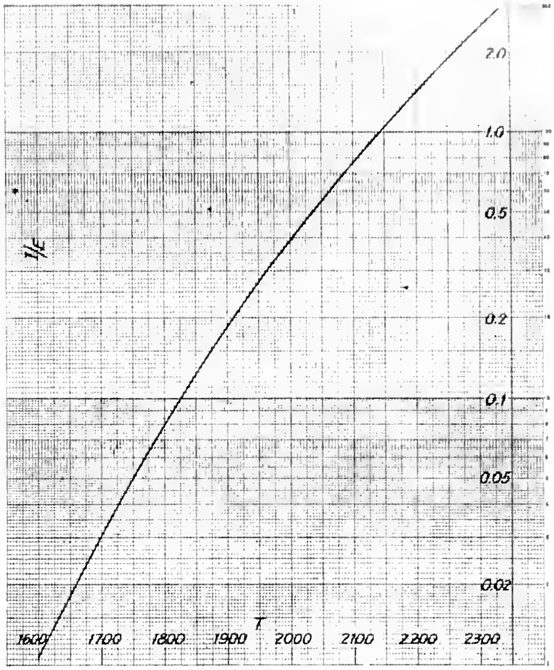


Fig. 9. Electron Emission per Watt for Thoriated Tungsten as Function of Temperature

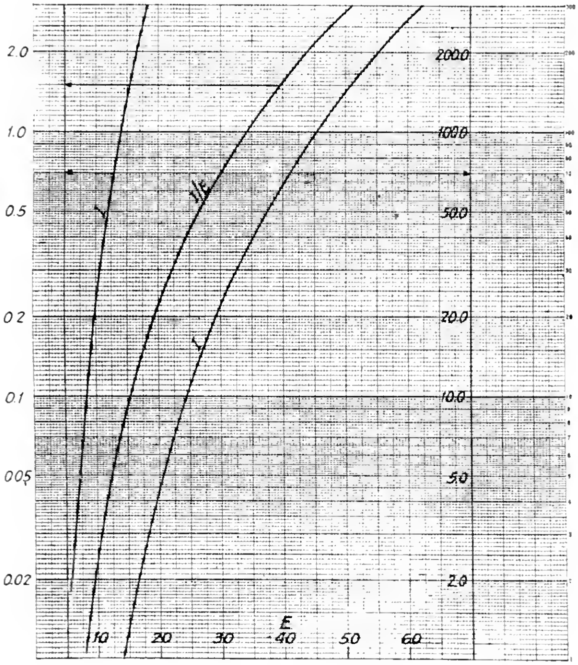


Fig. 10. Efficiency of Emission for Thoriated Tungsten as Function of Watts per cm².

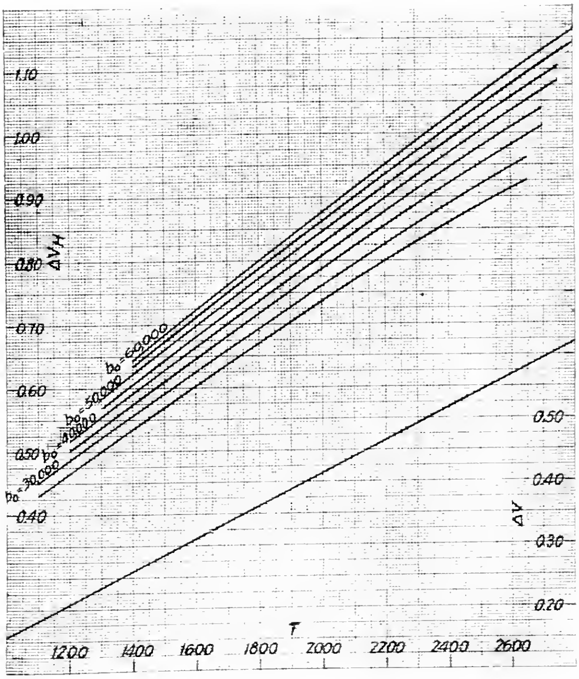


Fig. 11. Lead Loss Corrections

If log i_V is plotted against $\sqrt{V}$, a straight line is obtained and the value of log i_0 may be determined by extrapolation. The slope of this straight line, $\Delta \log i/\Delta \sqrt{V}$, varies inversely as T and from equation (8) it follows that

$$2.303\ T\ \Delta \log i/\Delta\sqrt{V} = 4.39\sqrt{k} \qquad (10)$$

Combining equation (8) with equation (2) it is evident that the electron emission per unit area at any voltage V is given by the relation

$$I_V = 60.2\ T^2\ \epsilon^{-\frac{b_0 - 4.39\sqrt{kV}}{T}} \qquad (11)$$

Hence if emission data obtained with a given anode voltage are used to calculate the value of b_0, this value is *lower than the true value* by the amount $4.39\ \sqrt{kV}$.

Table IV gives values of this correction for different cases in which k can be calculated by means of equation (9), the value of V being taken as 100 volts. These corrections correspond in magnitude to those which may be expected in ordinary thermionic devices.

TABLE IV

DECREASE IN b_0 AT $V=100$ FOR FILAMENT IN AXIS OF CYLINDRICAL ANODE

Diameter of Filament	Diameter of Anode	$4.39\sqrt{100\ k}$
0.001 cm.	1.00 cm.	747
0.005 cm.	0.50 cm.	409
0.005 cm.	1.00 cm.	381
0.01 cm.	1.00 cm.	289
0.1 cm.	1.00 cm.	129

Studies in the Projection of Light

PART II

PARABOLIC CYLINDER AND ELLIPSOIDAL REFLECTORS

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

In Part I of this series, a method of optical analysis employing meridian and sagittal lines was first explained and then applied to a study of the light projecting characteristics of a reflecting paraboloid (parabolic reflector). Students of optics should familiarize themselves with this rather unique scheme of analysis because it readily permits the investigation of complicated problems and is free from the pitfalls that are present when a light source of finite size is considered as a point source. The method is applied in this installment to the analysis of the fan-shaped distribution of light from a parabolic cylinder reflector (parabolic trough). The extraordinary characteristics of this type of reflector are clearly explained. The latter half of the article is devoted to an examination of the ellipsoidal reflector whose light-gathering and projecting properties have always appeared exceptionally attractive theoretically but have been incapable of application to practice except at very low efficiency because of the lack of a suitable light source. This reflector would seem to have a very promising future now that lamps having a highly concentrated filament are becoming available.—Editor.

PARABOLIC CYLINDER REFLECTOR

In several types of illumination, of which stage illumination is perhaps the most familiar, there is use for a reflector that will give a fan-like beam. There are two fairly simple ways of obtaining this beam formation. One is by the use of a set of cylindrical lenses in front of a parabolic mirror; and the other is by the use of a parabolic cylinder reflector, which is often called a trough reflector. The latter is much the simpler device and is very widely used.

The trough is formed by bending a flat sheet of metal so that it takes a parabolic curve, while at right angles to the curve the elements of the reflector are straight lines. The optical action is unique and is worthy of study. The analysis of the surface is best made by means of lines similar to the meridian and sagittal lines employed in Part I of this article, but it is first necessary to redefine these surface elements to fit the changed geometrical conditions. In Fig. 7 the line $V_0\ P_0\ E_0$ is parabolic in form, while $V_0\ V$, the transverse axis, and $E_0\ E$, the upper edge of the reflector, are straight lines. Let us call any parabolic curve in the surface parallel to $V_0\ P_0\ E_0$ a sectional line, and any straight line in the surface parallel to $V_0\ V$ an elemental line. It will be noted that whereas the meridian lines of the paraboloid, previously discussed, all passed through the axis of the surface of revolution, in the case of the parabolic cylinder the sectional lines are parallel and have no crossing points. Also, the elemental lines in the case of the latter reflector are all straight parallel lines.

Any incident ray as r_0, Fig. 7, parallel to the axis of projection $V_0\ X_0$ will be reflected to the focal point A of the parabolic section $V\ P\ E$. Similarly, parallel rays $r_1\ r_2$ in the same sectional plane will converge on the point A. Call the angle of convergence c and the distance from the point of reflection to the focal point p, then

$$p \tan \frac{c}{2} = PP_1 \cos \frac{a}{2} = PP_2 \cos \frac{a}{2} \qquad (18)$$

where the points P, P_1 and P_2 are close together on the sectional line. The incident ray r_0 lies in the intersection of a horizontal plane (determined by the elemental line $P_0\ P$ and the ray r_0 which is parallel to the axis $V_0\ X_0$) and a vertical plane cutting the surface along the parabolic sectional line. After reflection at the point P the ray r_0 lies in an oblique plane determined by the elemental line $P_0\ P$ and the radius vector p. If the ray r_0 is rotated in the horizontal plane through the angle e the reflected ray will rotate through the same angle e in the oblique plane and pass through point A_0 of Fig. 7. Similarly, incident rays r_1 and r_2 will after reflection converge on A, and when rotated each in its own horizontal plane through the angle e the reflected rays will pass through A_0 which is thus a converging or focal point, providing only that the distance $P_1\ P_2$ is extremely small.

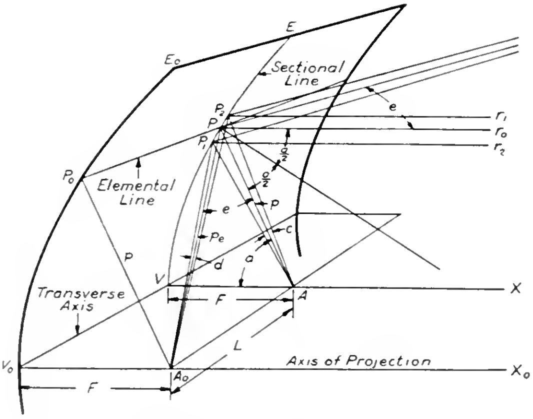


Fig. 7. Optical Characteristics of a Sectional Line in a Parabolic Cylinder Reflector

The convergence of the rays is changed by the rotation through the angle e. The length of the radius vector from A to P is

$$p = F \sec^2 \frac{a}{2}$$

while the radius vector from A_0 to P is

$$p_e = F \sec^2 \frac{a}{2} \sec e \qquad (19)$$

therefore $\qquad p_e = p \sec e$

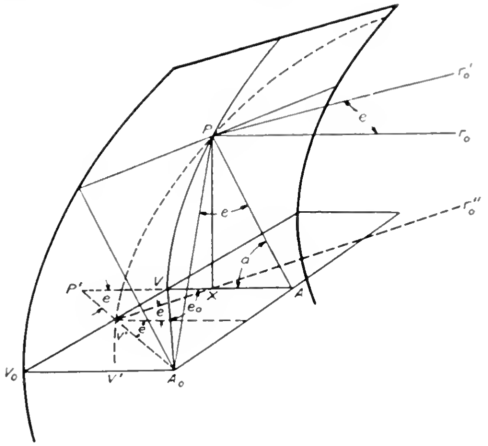


Fig. 8. Optical Characteristics of an Elemental Line in a Parabolic Cylinder Reflector

also
$$p \tan \frac{c}{2} = p_e \tan \frac{d}{2} \qquad (20)$$

and we get the relation

$$c = d \sec e \qquad (21)$$

after substituting the small angle c for tan c and angle d for tan d.

It will be shown shortly that the three rays r_0, r_1 and r_2 must be rotated through slightly different angles in order actually to converge upon the point A_0, and the latter is therefore not a focal point for the element $P_1\ P\ P_2$. We may place a point source at A_0 and the reflected rays at P_1, P and P_2 will lie in parallel horizontal planes but the values of e will become smaller as we pass from P_1 to P and to P_2.

The physical significance of equation (20) is that a point source of light may be moved along the line $A\ A_0$ and the reflected rays from various points in $P_0\ P$ will rotate in fixed planes that are parallel; or to take a different viewpoint, a fixed point source will have such of its light as strikes on a given elemental line $P_0\ P$ reflected at various angles in a single plane. This gives the fan-like beam previously mentioned, but it remains to be seen what the other properties of this fan beam are, and in particular how the angle of spread e is influenced by the proportions of the reflector.

In Fig. 8 a ray originating at A_0 and being reflected at the point P is shown as taking the direction $P\ r_0'$ after reflection. The angle between $P\ r_0'$ and $P\ r_0$, a parallel to the principal axis $V_0\ A_0$, is e, which we will call the angle of spread. It is useful to know how to cut the end of the cylinder so that the same maximum spread e will be obtained from all points along the ends. In Fig. 8 the triangle A_0 P A is shown rotated down into the horizontal plane, using the locus A_0 A as an axis, and the point P falls on P'. The length of the radius vector A P is A V (the focal length) plus X V, and therefore V P' is equal to X V. The triangle A_0 P' A is shown more clearly in Fig. 9. If the line V_0 V is considered to be a plane mirror, then P' is the image of X, and if V'' r_0'' is extended backward it will intercept the V_0 A_0 axis at A_0'. The latter point is a common crossing point for all rays reflected in the same horizontal plane, and therefore A_0' is a virtual image of A_0. Thus a ray from A_0 striking the reflector in the same horizontal plane as P will have the same X V distance and by the construction in dotted lines in Fig. 9 it is evident that for any angle f, which is different from e, the virtual image of A_0 will fall on the same point.

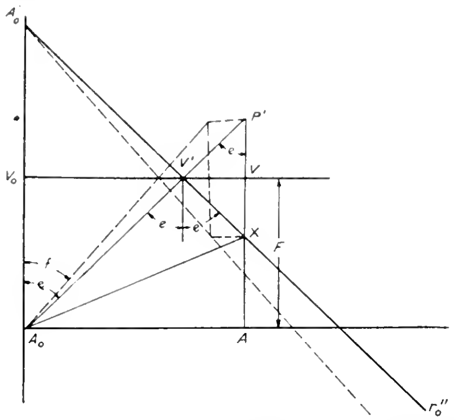


Fig. 9. Location of Virtual Image Points in a Parabolic Cylinder Reflector

We may thus regard A_0' as the light source; and if a total spread of say 50 deg. is desired an arc of 50 deg. swung about A_0' will include the necessary reflecting surface, 25 deg. on each side of the axis, and the ends will be formed by vertical planes cutting the parabolic cylinder.

The end pieces of the cylinder will themselves be parabolic in outline, with the apex of the parabola at the transverse axis of the reflector.

Given a parabolic cylinder with a section defined by

$$Y^2 = 4\ FX$$

and a desired spread of beam of $2e$ degrees, the outline of the end pieces will be the parabola.

$$Y^2 = 4\ FX \cos e \qquad (22)$$

and the oblique section of the reflector where it is joined by the end piece will of course have the same form but the developed form of the reflector end (dotted curve V'' P, Fig. 8) will not be parabolic. The ordinates of the developed curve (Fig. 10) will be the developed length of the parabola of equation (22) and the abscissae will be the abscissae of the original sectional line times tan e, or

$$X' = X \tan e \qquad (23)$$

Distribution of Light from Point Source

The beam from a parabolic cylinder has a highly characteristic outline, but its most interesting features are the internal relations between the various parts of the beam. These relations, which must be known if we are to make an intelligent or useful design of a reflector, are somewhat more complex than usual and the ordinary rules of photometric computation do not apply.

The illumination curves of Fig. 11a were worked out as an illustration of the distribution of light in a parabolic cylinder beam. The intensity of the light from the source at A_0 falls off as the inverse square of the distance until the reflecting surface is reached. Upon reflection the light is parallel in one direction and spreads according to its distance from A'_0 in the perpendicular (horizontal) direction. The decrease in intensity, therefore, follows the *inverse* law but not the *inverse square* law. As an example, take the light radiated 60 deg. upward from the axis ($a =$ 60 deg. in Fig. 11b) and at 30 deg.

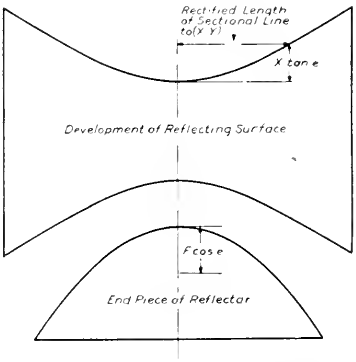


Fig. 10. Development of Parabolic Cylinder Reflector of 200-deg. Opening and 80-deg. Spread

to one side of the axis ($e = 30$ deg. Fig. 11a). This light after being reflected seems to come from the virtual image at A'_{60} and there is no divergence in the vertical direction, but in the horizontal direction the divergence is from the point $A'_{0\text{-}100}$ of Fig. 11a.

Let I be the intensity of radiation, in candles, given off uniformly in all directions by the point source at A_0. At any point P, Fig. 11a and 11b, the *normal* illumination is

$$E_n = \frac{I}{p_e^2} \qquad (24)$$

and from equation (19), after substituting the cosines for the secants, the expression for *normal* illumination at the distance p_e is

$$E_n = \frac{I}{F^2} \cos^4 \frac{a}{2} \cos^2 e \qquad (25)$$

After reflection at the point P the illumination on a normal surface will decrease as the inverse distance, hence at a distance D the illumination E_n' is in the proportion

$$\frac{E_n'}{E_n} = \frac{p_e}{D} \qquad (26)$$

or

$$E_n' = E_n \frac{p_e}{D}$$

After substituting from (24) we get

$$E_n' = \frac{I}{p_e D} \qquad (27)$$

The form of this equation is unique among equations in illuminating engineering in that it contains in the denominator two first-power variables p_e and D instead of the single second power variable D^2 that occurs when the inverse square law applies.

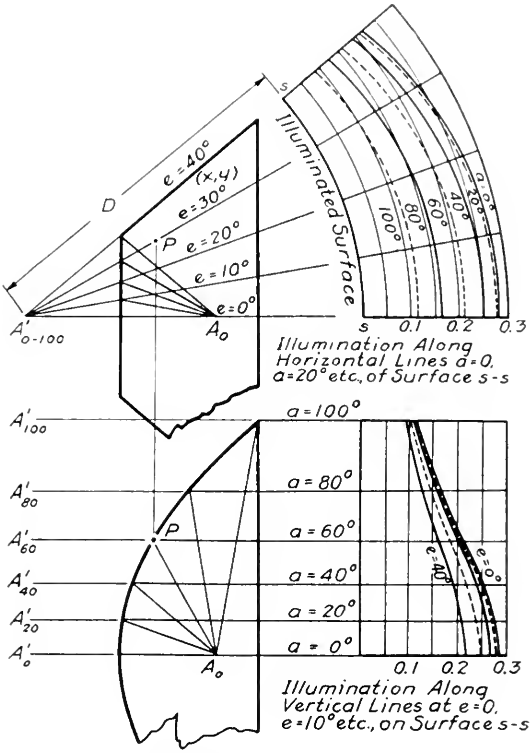
One striking result of the peculiar formation of the reflected beam is that one cannot measure the intensity of radiation in candles. The term "candle" can be applied only to radiation that gives illumination that decreases as the square of the distance. For this particular beam we therefore have radiation that has no name to describe its angular intensity, but the resultant illumination at a given plane may be computed as shown in equation (28) and, of course, expressed in foot-candles.

The illumination curves of Fig. 11a are along the intersections of horizontal planes (corresponding to $a = 0$, 20, 40, 60, 80 and 100 deg.) with the cylindrical surface $s\ s$ generated about the axis $A'_0\ A'_{100}$.

The illumination along the vertical lines where the planes for $e = 0$, 10 deg., etc , cut the cylinder is plotted in Fig. 11b.

If the illumination on a surface not normal but making an angle f with the incident light is desired, the equation of surface illumination is

$$E_s' = \frac{I \cos f}{p_e D} \qquad (28)$$



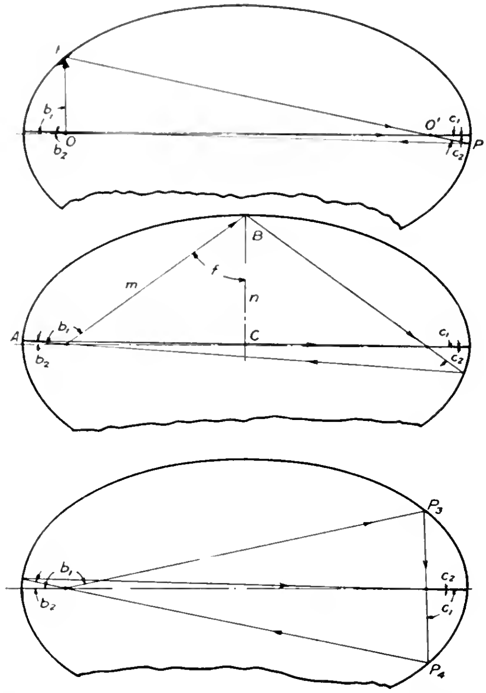
Figs. 11a (upper) and 11b (lower). Normal Illumination by Light Reflected from a Parabolic Cylinder; Plan and End Elevations of Reflector

The exactness of this equation for the reflector depends upon the closeness of the light source to the ideal "point" conception, and for the usual light sources other features must be taken into consideration. This is mentioned here as a reminder that the "point source" is an excellent starting point for theories of photometry, but the application of these theories to practice must usually be preceded by an expansion of the theories to cover the peculiarities of the source under investigation.

ELLIPSOIDAL REFLECTOR

Distribution of Light from Point Source

One of the most interesting properties of the ellipse or ellipsoid is the fact that light generated at one focal point is reflected to the other focal point, and thus the two foci are conjugate in the optical sense as well as in the geometrical sense. This being the case it is at once evident that the ellipsoid is a surface wonderfully adapted for collecting light on all sides of a light source and projecting it to a common point. For this reason, one might think that the ellipsoid should be frequently encountered in practice whereas there are extremely few actual applications. This form of reflector will without doubt in the future see wide use in the illuminating art, and it is purposed to set down here some of the fundamental optical properties of the surface and show why at the present time its application is so limited.



Figs. 12a (upper), 12b (middle) and 12c (lower). Three Examples of the Approach of Reflected Light to Parallelism with the Axis of an Ellipsoidal Reflector

In Fig. 12b is shown an ellipse with an ellipticity e of 0.8125, or

$$e = \sin f = \frac{\sqrt{m^2 - n^2}}{m} \tag{29}$$

where m is the semi-major axis CA and n is the semi-minor axis CB.

The point source of light is located at the left focal point O, Fig. 12a, and a ray radiated at an angle of 90 deg. from the axis, after reflection at the point P, will cross the axis at the conjugate focus at an angle of 10 deg. 54 min. After the second reflection at P' the angle at O will be 1 deg. 14 min. This approach of the reflected ray to the major axis continues indefinitely, and ultimately the light will pass back and forth in coincidence with the major axis. It is this feature of an approach to parallelism that makes the ellipsoid seem a useful optical surface, and with the development of manufacturing optics the ellipsoid may find wide service where a moderate concentration of light is desired.

The manner in which the light comes into a path nearly parallel with the axis is shown in Figs. 12a, 12b, and 12c, and also in Table I where the plus (+) sign indicates a path toward the right and the minus (−) sign a path toward the left.

The radiation from the source is assumed to be equal in all directions, but after the first reflection the bulk of the light passes through the O' focus in the positive direction and only a small part has a backward direction. On the second reflection all the light has a negative direction and the whole quantity of light is thereafter positive and negative in direction of passage.

In the particular ellipse chosen there is 90 per cent of the light reflected with a component to the right, and only 10 per cent with a component to the left. This is a high collecting efficiency for a reflector, and if the ellipsoid is cut off along the section $P_3\ P_4$, Fig. 12c, the direct radiation, amounting to 10 per cent, that was turned to the left will now radiate directly out through

TABLE I

	Fig. 12a	Fig. 12b	Fig. 12c
Radiation	b = 90° 0′ 0″	+125° 40′ 0″	+168° 6′ 0″
1st reflection	c_1 = +11° 54′ 0″	+ 35° 40′ 0″	90° 0′ 0″
2nd reflection	b_2 = — 1° 14′ 0″	— 3° 20′ 0″	— 11° 54′ 0″
3rd reflection	c_2 = + 0° 7′ 44″	+ 0° 20′ 42″	+ 1° 14′ 0″
4th reflection	b_3 = — 0° 0′ 48″	— 0° 2′ 8″	— 0° 7′ 44″
5th reflection	c_3 = + 0° 0′ 5″	+ 0° 0′ 13″	+ 0° 0′ 48″
6th reflection	b_4 = — 0° 0′ 0.5″	— 0° 0′ 1.4″	— 0° 0′ 5″

the opening and the entire light from the unit will pass out of the open end of the ellipsoid in a positive direction.

The radius of the circle about the left focus of Fig. 13 represents the intensity of radiation from the light source, and the oval curve about the right focus is the radiation about the image formed on the first reflection. The intensity along the axis in the positive direction is multiplied by nearly a hundred, while in the negative direction the intensity is about one-hundredth.

It might be here remarked that the area of a photometric distribution curve is never a direct measure of the total quantity of light. The quantities of light about the two foci are of course equal if the ellipsoid is complete.

The radius vector (or path of incident ray) at any angle b, Fig. 13, is

$$r=\frac{m(1-e^2)}{1+e\cos b} \qquad (30)$$

and the path of the reflected ray to the conjugate focus is

$$2m-r=r'$$
$$=\frac{m(1-e^2)}{1+e\cos c} \qquad (31)$$

The intensifying factor is the ratio of the square of r' and r, or

$$f=\left(\frac{2m-r}{r}\right)^2 \qquad (32)$$

which may be also given in the form

$$f=\left(\frac{1+2e\cos b+e^2}{1-e^2}\right)^2 \qquad (33)$$

or when both angles are known

$$f=\left(\frac{1+e\cos b}{1+e\cos c}\right)^2 \qquad (34)$$

The proof of equations (32), (33) and (34) is based on the photometric law that the illumination varies inversely as the square of the distance and directly as the cosine of the angle of incidence. The elemental zone area dA of Fig. 13 extends around the ellipsoid at a uniform distance of r from the source and its illumination is therefore

$$E=\frac{I}{r^2}\cos i \text{ foot-candles} \qquad (35)$$

if the intensity I of the source is expressed in candles and the distance r is expressed in feet.

The light reflected from dA, assuming the surface to be perfect in both formation and reflecting power, is concentrated on O' at a distance r'. The foregoing law of radiation is independent of the direction of radiation so that while dA is the illuminator and the point O' the illuminated, we can again write

$$E=\frac{I'}{(r')^2}\cos i \qquad (35a)$$

where I' is the intensity of received radiation and r' is the distance from dA to O'.

Equating (35) and (35a) we get

$$I'=I\left(\frac{r'}{r}\right)^2 \qquad (36)$$

which is the equivalent of the equations for the intensifying factor.

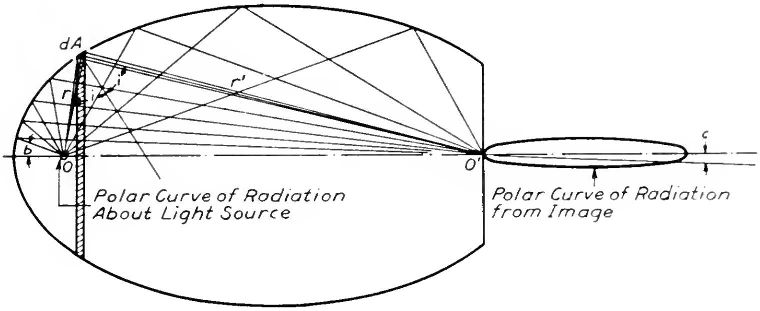


Fig. 13. Distribution of Light about the Source and the Image at the Conjugate Foci of an Ellipsoidal Reflector

It is at this point that the difficulties of a practical application of the ellipsoid begin. The distribution of intensities about the conjugate focus are not widely different from the computed values for any of the usual light sources that suggest themselves, and thus the "point source" and the actual source are thus far in fair agreement. The feature that has been overlooked is the fact that there is an enlargement or reduction of the image at O' depending upon the path taken by the light, and this enlarging or *area* factor is identical with the intensifying factor of equations (32), (33) and (34). The radiation from the image at O' is $\left(\frac{2m-r}{r}\right)^2$ times as great because the image has changed its sectional area to that extent. The brilliancy of the image is in every case equal to that of the brilliancy of the source times the coefficient of reflection, and from every angle of view the image at O' has a brilliancy

$$B'=KB \qquad (37)$$

where B is the brilliancy of the source and K is the coefficient of reflection of the surface of the ellipsoid.

Distribution of Light from Finite Source

In Fig. 14 is shown a half-ellipsoid which was so mounted that the image at the external focus was in the proper position to send light through the condensing lenses, lantern slide, and projection lens to the screen.

The dimensions of the ellipsoid were:

Semi-major axis. . . . . . 8.00 in.
Semi-minor axis. . . . . . 5.00 in.
Ellipticity. 0.78

The distance from the lamp focus to the center of the reflector, which in this case was cut away to make room for the lamp base and socket, was, from equation (30)

$$r = \frac{8\ (1-0.61)}{1+0.78} = 1.75 \text{ in.}$$

and the enlarging ratio *d*, in *diameters*, is derived from equation (32)

$$d = \frac{2\ m-r}{r} \qquad (38)$$

$$= 8.15$$

The diameter of the light source was 0.36 in. and this would have made an image diameter of 2.9 in. The enlargement ratio of the condensers, for an image in the center of the objective lens, was 3.5 so that the second image in this plane would have been 10 inches in diameter. The objective had a diameter of only 1.5 in. and it is very evident that for a central image this optical combination was very wasteful, the computed efficiency being 0.02. As a matter of fact, in this particular experiment the lamp was moved ahead of the focus of the ellipse, reducing the enlarging ratio at the conjugate focus to 7, and the image diameter at the objective to less than 8.8 in.

Light reflected from the rim of the reflector formed an image of about the size of the light source itself (r and r' being equal) and so far as size was concerned this image was highly efficient in passing through the objective to the screen The actual projection efficiency of the reflector thus varied from 2 per cent in the center to nearly 100 per cent at the rim. At a point directly above the lamp the enlarging ratio in *diameters* is, from (33)

$$d = \frac{1+2\ e\cos b+e^2}{1-e^2} \qquad (39)$$

$$= \frac{1+0.61}{1-0.61} = 4.1$$

and this gave an image at the conjugate focus 1.35 in. in diameter, and a second image at the objective 4.7 in. in diameter. The efficiency of this region of the reflector was 10 per cent. As more than half the light collected by the reflector fell in regions having efficiencies between 2 and 10 per

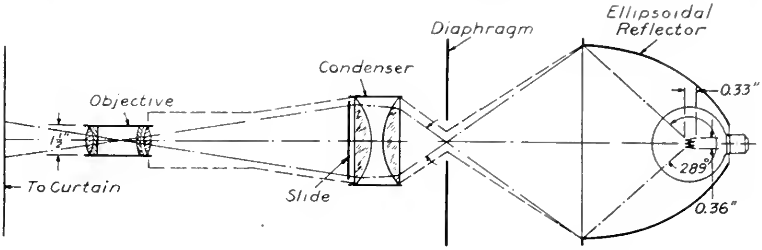


Fig. 14. First Example of the Application of an Ellipsoidal Reflector to Lantern-slide Projection

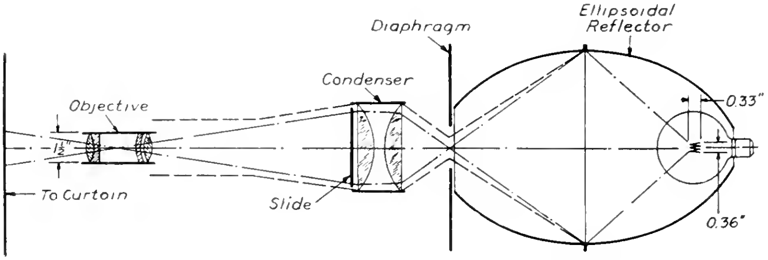


Fig. 15. Second Example of the Application of an Ellipsoidal Reflector to Lantern-slide Projection

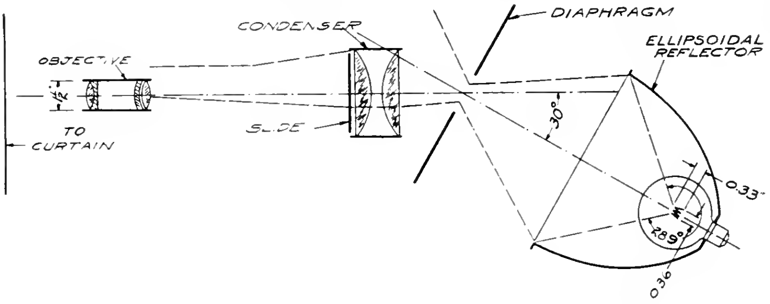


Fig. 16. Third Example of the Application of an Ellipsoidal Reflector to Lantern-slide Projection

cent, and less than half was over the latter percentage, it is evident that the net efficiency of the reflector for this particular test and with this particular lamp must have been low.

If we assume that the light from the bare lamp was equally distributed in all directions, the percentage collected by the condensing lens with the lamp in its usual position (the first condenser subtending an angle of 71 deg. from the lamp center) was

$$f=\frac{1-\cos 35° 30'}{2}=0.093$$

The amount of light within any given angle e from the axis of a uniformly radiating source is proportional to the corresponding area of an enclosing sphere of unit radius. Suppose this sphere to be surrounded by an open ended cylinder of radius 1, so that its center is tangent to the equator of the sphere and its length is equal to its diameter. A plane perpendicular to the common axis cuts equal areas from the sphere and cylinder, and in the latter surface the area is obviously the diameter of the cylinder times the length (from the 0 deg. end) cut off.

Thus

$$A=2\pi(1-\cos a)$$

or, in terms of the entire cylindrical surface

$$\frac{A}{4\pi}=\frac{1-\cos a}{2}$$

The half ellipsoid collected light up to 141 deg. from the axis with a collecting efficiency of

$$\frac{1-\cos 141 \text{ deg.}}{2}=0.823$$

or 8.8 times the condenser collecting efficiency. Assuming a coefficient of reflection of 0.8 for the ellipsoid, and taking 0.12 as being the average projection efficiency for this particular ellipsoid, the total projected light would amount to 0.079 of the initial light of the lamp. This figure of 0.079 is not greatly different from the corresponding figure of 0.093 for the condensing lenses alone. A visual and photographic comparison of the screen illumination showed the two to be nearly equal, and the foregoing rough computations are thus known to be fairly exact.

The apparent outlines of the light reflected from the ellipsoid of Fig. 14 are marked with a dotted line. These outlines do not represent the true edge of the beam, but rather the place where there was visible a marked falling off in intensity. This follows searchlight practice, wherein the edge of the beam is that point of the beam where the intensity falls to 10 per cent of the maximum, or central, intensity.

A repetition of the experiment with a reflector reaching the plane of the front focal point, Fig. 15, gave only slightly better screen illumination, as might be expected in view of the small amount of additional light collected (some 15 per cent) and the return of this light after two reflections in such a direction as to strike the lamp base or the opening in the rear of the reflector.

A further test was made with the half ellipsoid turned at an angle of 30 deg. with the axis of the projection machine, Fig. 16. The losses were found to be excessive at both condenser and objective, and only one edge of the lantern slide could be projected onto the screen.

The same ellipsoidal reflector that performed so poorly with a lamp having a filament 0.36 in. across the outer coils would be a fairly effective device with the proper lamp. Thus, if we go through the previous computations in the reverse order, we find that with lamp filaments that are now available the reflector should be quite efficient.

We have:

Permissible image at objective, 1.5 in. diameter

Enlargement ratio of condensers 3.5

Permissible image at front focus 0.43 in. diameter

Maximum enlargement ratio of reflector 8.15

Maximum diameter of filament coil 0.053 in.

With a filament of 0.05 in. or 0.06 in. outside coil diameter the successive images would thus be within optical bounds and the high collecting efficiency of this ellipsoid would be of great value in increasing the curtain illumination per watt of lamp input. The advantage here is purely a matter of economy, as the ultimate screen illumination is always less with a small source and a reflecting surface than with a large source used directly. Thus with a source of sufficient size used directly at the focal point of the condensers the illumination at the screen is, say, 10 foot-candles, while with a source of the same brilliancy used in connection with an ellipsoidal reflector the maximum attainable illumination will be 8 foot-candles, but this latter source may be of much smaller size and wattage.

(*To be continued*)

Electrification of the Massachusetts Cotton Mills, Lindale, Ga.

By D. W. Peabody

Atlanta Office, General Electric Company

Electrification produces results economically regardless of whether the drives required are one or many and whether the individual power demands are great or small. Among the conspicuous examples may be mentioned the mine hoist, steel mill, electric railway, machine shop, and textile mill. The following article describes a recent installation of electric drive in the last named industry. The figures of the production economy thus secured are of inestimable value because they were secured by comparison with the parallel operation of a similar mill which employs straight mechanical drive.—Editor.

The Massachusetts Cotton Mills at Lindale, Ga., were originally designed and equipped for mechanical drive throughout. They have more than 100,000 ring spindles, 2734 narrow and 460 broad looms, and produce sheeting, shirting, duck, drills, denims, and canton flannel. The mills are divided into three units, which are independent from a power standpoint.

One of these units, known as Mill No. 1, with 35,000 spindles, has recently been changed over from mechanical to electrical drive throughout and the remaining two mills will also be electrified but at present are operating with the original mechanical equipment. This particular installation is of unusual interest in that practically identical mechanically and electrically operated mill equipments are engaged in simultaneous production under conditions which permit of a ready comparison of the operating characteristics and productive efficiency of the two methods of drive.

Originally all three units of these mills were driven by low-speed reciprocating steam engines, operating condensing with steam at 145 lb. and connected to the main driving shafts on the three floors of the mills by rope drive; the various countershafts on each floor being driven by belts from the main shaft. This method of drive involved the use of an enormous amount of belting. The electrification of Mill No. 1 eliminated more than 200 of these belts and incidentally eliminated the loss in power which had previously been involved in the belt slippage. About 25 per cent of the belting consisted of heavy countershaft drives, the remainder being the belts from the countershafts to the machine pulleys. The estimated loss of power amounted to more than 10 per cent of the total primary power.

These conditions, serious as they were from an engineering standpoint, would not have warranted the electrification of the mill if no other benefits were to be derived from electric drive. It had already been demonstrated, however, in a number of cotton mill installations, that the constant speed characteristics of the electric motor permitted the operation of a large part of the textile mill machinery at higher speeds than could be safely obtained with mechanical drive, and that these speeds could be maintained with absolute uniformity. Therefore, the results to be obtained in the electrification of this mill (in addition to the saving effected in the power cost of production) would be the much more important increase in production secured without any increase of the textile mill machinery.

The changeover was not made until after exhaustive tests had been made with temporary electrical equipment.

The power station equipment (Fig. 1) consists of a 6000-kw., 3600-r.p.m., 600-volt, 3-phase, 60-cycle steam turbine-generator, operating condensing at present at 190 lb. boiler pressure. This turbine is intended eventually to supply current for all three mills, and when the remainder of the electrical equipment is installed it will then be operated with 100 degrees superheat. There is also a 600-kw. turbine-generator which is utilized to carry the night loads; such as fire pumps and mill, house, and street lighting in the mill village.

The operating economies of the electrified plant begin in the power station. The floor space required by the turbine-generator is less than one-third of that occupied by the original engine (Fig. 2), and the higher overall efficiency of the modern steam turbine reduces the boiler capacity required for a given power output and this saving is reflected in the amount of coal used. Even under present conditions, with the generating set operating underloaded, and therefore at relatively low efficiency as compared with full-load operation, there has been secured an actual average saving of about 40 tons of coal per week.

The leads from the main turbine-generator are brought direct to a framework (Fig. 3)

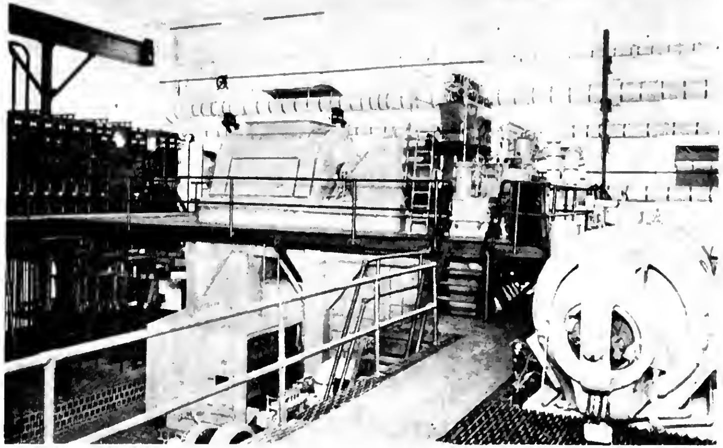


Fig. 1. General View of Power Station showing 6000-kw. 3600-r.p.m. 600-volt Turbine-generator Operating Condensing at 190 lb., 600-kw. Turbine-generator, and Main Switchboard

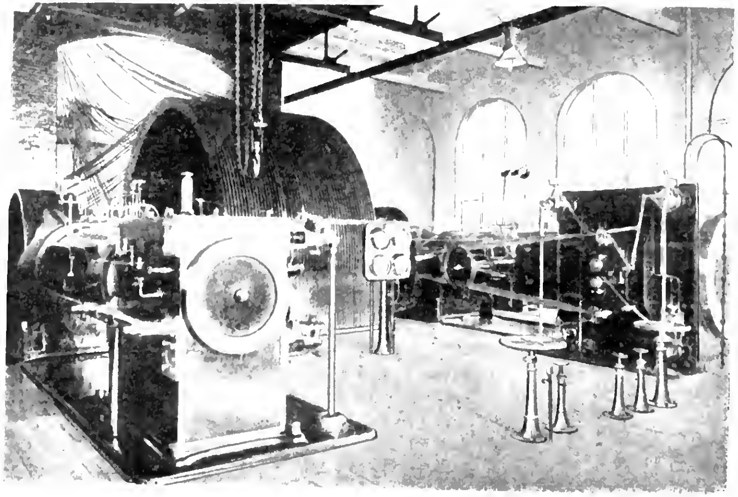


Fig. 2. Original Engine Drive for Mill No. 1. Superseded by Turbine shown in Fig. 1

Fig. 3. Arrangement of Main Busbars between Generator and Switchboard

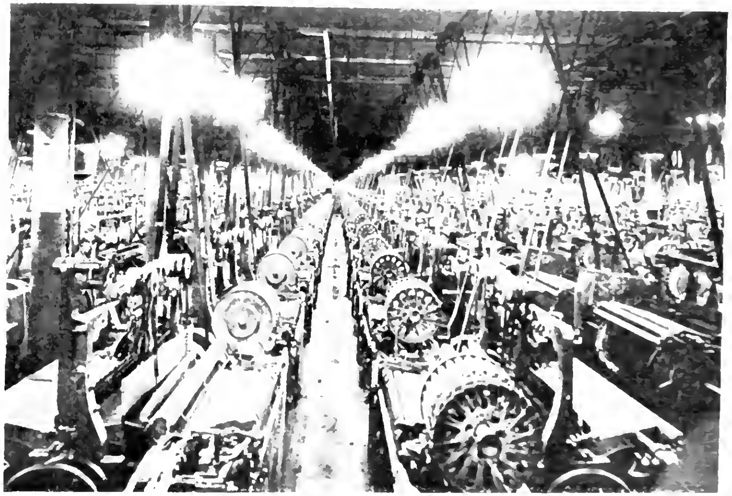


Fig. 4. Night View of Weave Room showing Each Loom Lighted by a 75 watt Mazda Lamp with RLM Metallic Reflector

which contains the main busbars, and is provided with 12,000-ampere automatic air circuit breakers which are solenoid operated from the main generator panel and controlled by relays from the main switchboard which is located on the floor above. This arrangement insures absolute safety to the operator through remote control.

Current is distributed through eight feeder circuits. The outgoing feeder wire from the switchboard is all enclosed in metallic conduit, the distribution to the mill being made at 600 volts. The motors used are rated at 550 volts. Current for the lighting circuit is stepped down by transformers outside of the mill to 120 volts and Mazda lamps with standard metallic Type RLM reflectors are used throughout (Fig. 4).

The picker room equipment includes nine opener pickers each individually driven by a 10-h.p. motor mounted on the A-frame and provided with three pulleys from which short belts go to the beater shafts.

Ten intermediate single-beater pickers are each equipped with a 7½-h.p. motor, while the finisher pickers (Fig. 5), of which there are ten, are provided with 5-h.p. motors. These are all individual drives and the control of each consists of an oil circuit breaker mounted on the A-frame of the picker.

In the changeover of the picker room to electric drive, three countershafts with their main belts, pulleys, and about thirty belts were eliminated. When this room was mechanically driven, the shutdown of one or more machines resulted in no appreciable reduction in the amount of power required, and if only one or two machines were operating the power consumed by the belts and countershafts was practically as great as that involved in the operation of all the machinery.

With electric drive it is possible to operate any of the machinery intermittently with only the normal unit consumption of power. With individual motor drive the power consumed is directly proportional to the work produced and the supply of energy to each machine stops when the motor stops.

In the card room segregated group drive (Fig. 6) has been used throughout with the driving motors mounted on the ceiling in an inverted position and utilizing totally-enclosed chain drive to the center of relatively short countershafts. With this arrangement high-speed motors can be used with a corresponding reduction in their physical dimensions and cost, and they can be connected to the countershafts with short centers.

The control for each group consists of a standard compensator located in a place convenient to the operator, and the subdivision of power application permits economy in the operation of part of the machinery.

The slubbers and intermediates are also motor group driven and have the same general arrangement as the cards.

The spinning room* was originally equipped with the so-called "bicycle drive," involving the use of long countershafts, with more than 150 large and 300 small pulleys with belts connected to the individual frames. It was an excellent example of mechanical drive and was maintained in good condition by careful alignment of the shafting, frequent inspection, and adjustment of belt tension and adequate lubrication but it was not possible to maintain the front roll speed of the frames at a rate which would give the best production.

In making the changeover to individual electric drive it was not necessary to alter the location of the machines, and the motors were mounted on brackets which utilized the original spinning frame bolt holes. The original spacing of the frame ends, while it was narrow, afforded ample room for the installation of the motors, chain drive, control, conduit wiring, and totally-enclosed protective devices which constitute a compact self-contained and independent power unit for each spinning frame.

The motors used* are 7½-h.p., 1800-r.p.m. units and are individually controlled by a non-automatic circuit breaker operated by means of a shipper rod. The wiring to the motors is brought up through the floor and all wiring between the motor and the control is enclosed in flexible metallic conduit.

The application of individual drive in this case was due to a realization of the importance of constant speed as compared with the varying speed which was unavoidable in the use of mechanical drive; and the improvement in both the quantity and quality of the output, which result has been very marked.

While it was desired to operate with a front roll speed of 148 r.p.m., to obtain the best production, it was found necessary with the mechanical system to reduce this to 144 r.p.m., and at this speed the average "ends down" was two per cent. After the individual motors were applied to these same frames, it was found possible to increase the front roll speed to 154 r.p.m., and at this increased rate of speed the average "ends down" was somewhat less than one-half of one per cent. In

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* See cover illustration of this issue of the **Review.**

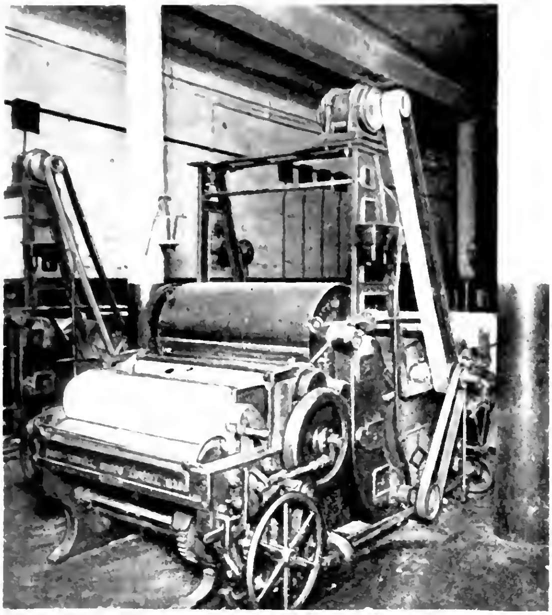

Fig. 5. Pickers with 5-h.p. Picker-type Motors Mounted on A-Frame

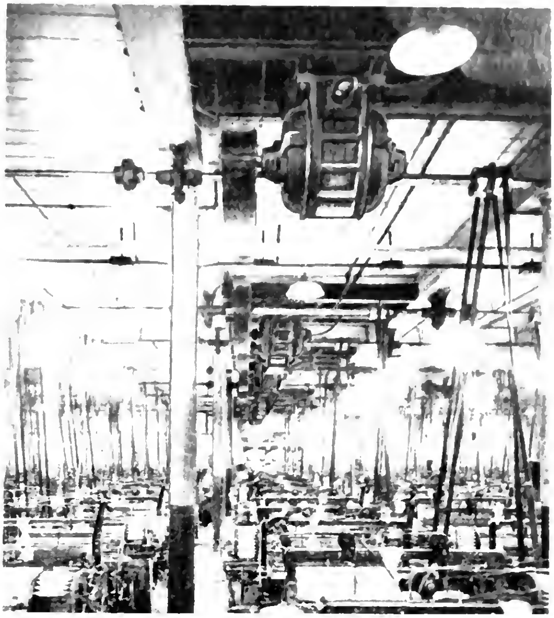

Fig. 7. Induction Motors Mounted on Ceiling and Driving Weave Room Through Chain-driven Countershafts

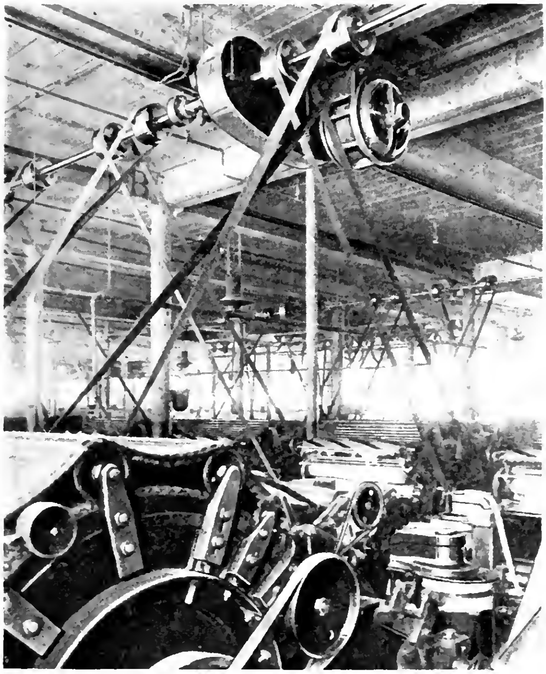

Fig. 6. Induction Motors in Card Room with Chain Drive to Countershaft

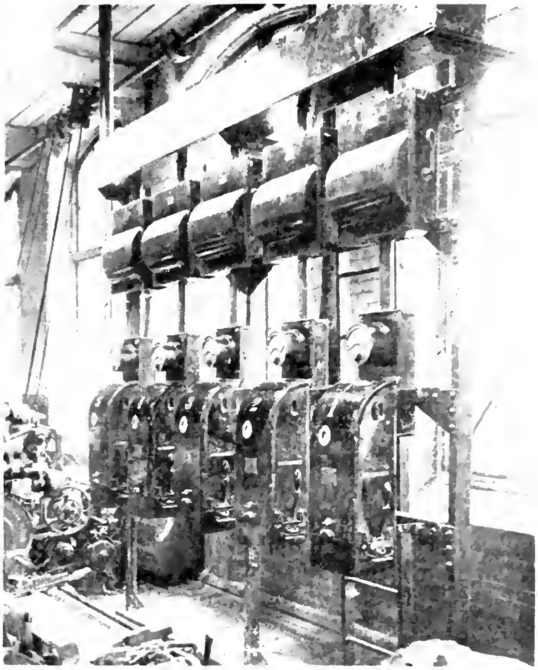

Fig. 8. Group of Starting Compensators for Controlling Weave Room Motors

addition to the actual increase in production, there was a definite improvement in the quality of the yarn produced.

The spoolers, warpers, and slubbers are all provided with light group drive with small motors mounted inverted on the ceiling and belted to the countershafts.

In the weave room of a new mill it is customary for the loom manufacturer to provide individual motors for each machine as a standard equipment, but in the case of Mill No. 1 it was found that the mechanical changes necessary to provide individual drive in the weave room would involve an expense that was not warranted under the existing conditions, and a system of group drive was therefore adopted. With this change each line of countershafts is provided with its own motor (Fig. 7) thereby eliminating the large main belts which were previously used and permitting the economical operation of separate groups of the machinery on overtime work.

With the elimination of the main line belts and with the motors driving light groups of looms, the number of interruptions due to belt slip has been greatly reduced and with an increased output there has been a positive improvement in the quality of the loom products.

The motors are mounted on the ceiling with short enclosed chain drives and the control for the various groups of machines is concentrated in groups of compensators installed on angle-iron frames at the sides of the weave room. These compensators (Fig. 8) are each equipped with a switchboard type ammeter and a safety switch.

A thoroughly modern system of illumination has been provided throughout the mill; Mazda lamps with standard metallic type RLM reflectors being used. The most intensified illumination is found in that section of the weave room devoted to colored goods, and in this case (Fig. 4) each loom is provided with a 75-watt lamp.

While the motors are all operated on 550-volt circuits, special lighting transformers are provided to give 120 volts for the lighting circuits; and the same service is provided for the houses of the mill operatives and streets of the mill village as well as for the churches, school, gymnasium, clubs, theaters, hospitals, and recreation buildings, all of which are maintained by the mills.

Without any increase in the textile mill machinery used, Mill No. 1 has shown an overall increase in production of about 12 per cent for the electric drive as compared with the former mechanical drive.

Radio Transmitting Sets for the Mexican National Radio System

By B. R. Cummings

Radio Engineering Department, General Electric Company

To the average individual in this country the mention of radio brings to mind only the fascinating interest that is connected with the reception of the entertaining programs which are broadcast daily. For him it would be instructive to learn of the less sensational but more valuable application of radio to commercial communication. For example, the Government of Mexico proposes to cover its territory with a network of radio telegraph stations furnished with the most modern vacuum-tube equipment. This plan calls for the installation of some 42 radio "central stations" and "substations," the first sets for the purpose being described in the following article.—Editor.

The functioning of vacuum-tube transmitters, in general, has been discussed in previous issues of the General Electric Review* and therefore the present article will be confined to a description of two types of transmitters which have recently been developed and built for installation in Mexico. These will form part of an elaborate radio telegraph communication system in that country.

Their characteristics and ratings were established after a comprehensive study of the communication requirements in connection with stations already in service. In the selection of the capacities advantage has been taken of the superior transmission effectiveness of continuous-wave (vacuum-tube) transmitters; and in general capacities have been selected which will insure twice the signal strength that is now obtained from spark transmitters which employ double the power input to the antenna.

The system contemplated involves the erection of forty-two stations, in addition to those already in operation. Of the new stations, four will be so-called "central stations" and will communicate with a

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* "Radio Communication," by W. R. G. Baker, September, 1922, p. 535.

"Commercial Radio Telephone and Telegraph Transmitting Equipment," by W. R. G. Baker and B. R. Cummings, October, 1922, p. 603, and November, 1922, p. 666.

number of smaller "sub-stations." The new central stations will be located at Puerto Morelos, Puerto Mexico, Monterey, and Culiacan. Those already in operation or under construction are located at Mexico City, Tampico, Torreon, and Hermosillo.

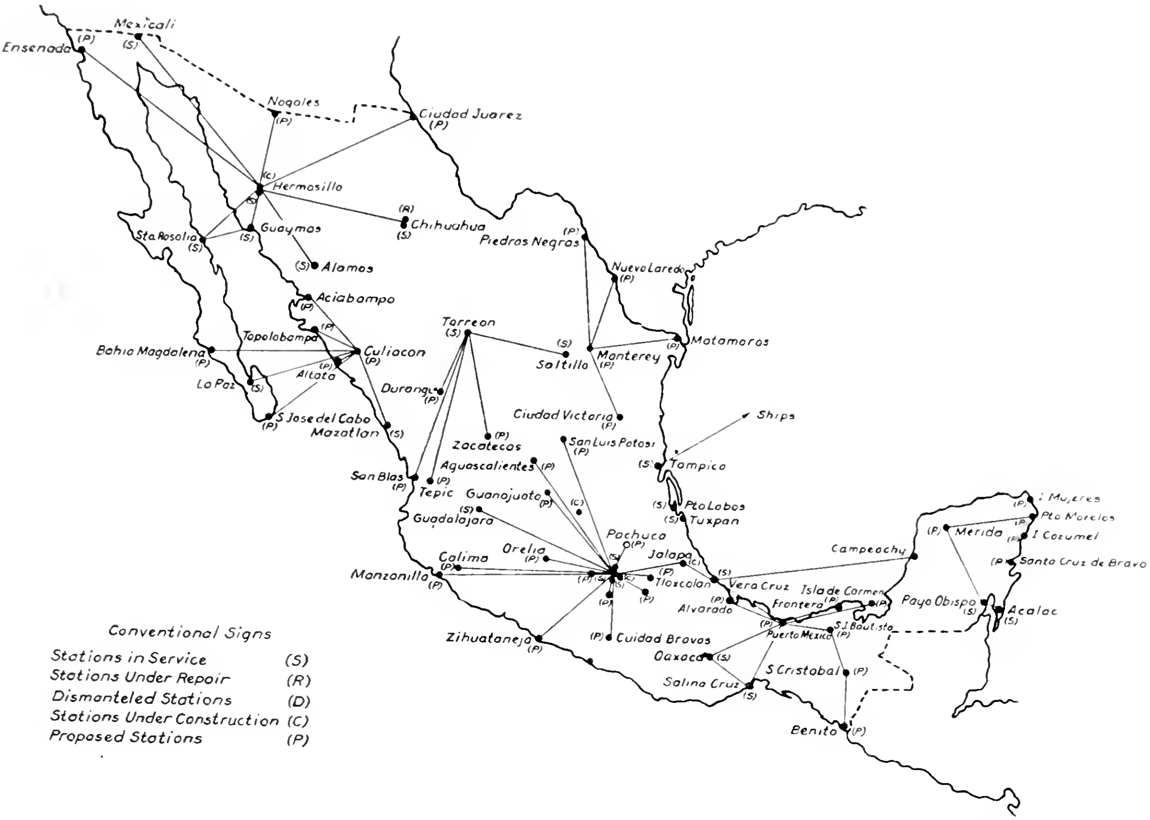


Fig. 1. Map of Mexico showing the Location of Stations for the Proposed National Radio Telegraph System

Transmitters of the type described in this article will be installed at the new central stations as follows:

Station	Capacity	Maximum Communication Distance Required
Puerto Morelos	2 kw.	172 miles
Puerto Mexico	2 kw.	172 miles
Monterey	2 kw.	202 miles
Culiacan	4 kw.	280 miles

The map shown in Fig. 1 illustrates graphically how completely the proposed system covers the Republic of Mexico.

These transmitters are rated at 2 and 4 kw. respectively, putting that amount of power into the antenna circuit. This point should be remembered in comparing their output with that of spark or arc transmitters, since the latter are almost universally rated in terms of "input" to the transmitter or arc converter.

The vacuum-tube sets are built to operate on any wavelength between 600 and 3000 meters, when used on an antenna having the characteristics specified in the following paragraphs. By means of wave-change switches any one of four predetermined wavelengths may be selected in minimum time.

These sending equipments are designed to operate on an umbrella-type antenna having two distinct sections. The upper section is used to obtain wavelengths from 1200 to 3000 meters. It has approximately the following characteristics:

Fundamental wavelength	770 meters
Capacity	0.0027 microfarads
Resistance	3.9 ohms at 1500 meters 2.4 ohms at 3000 meters

The lower section is used to obtain wavelengths from 600 to 1200 meters, and has approximately the following characteristics:

Fundamental wavelength	400 meters
Capacity	0.00086 microfarads
Resistance	11. ohms at 600 meters 4. ohms at 1200 meters

Antennas of other forms, having the same characteristics, can be used.

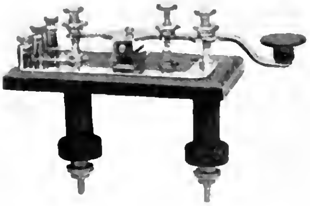


Fig. 2. Relay Key

Fig. 3. Operator's Control Cabinet

Provision is made for telegraph transmission either by continuous waves (c.w.) or interrupted-continuous waves (i.c.w.) Transfer from one method to the other is made by throwing a single switch, which makes all necessary changes in the circuit connections.

While continuous-wave transmission has greater transmission effectiveness than interrupted-continuous-wave, the latter is provided so that communication can be carried on with ships and shore stations not equipped for the reception of continuous-wave signals. The interrupted-continuous-wave signals can be heard by all stations equipped for spark reception.

The keying system includes a so-called "break-in" relay, whereby the antenna is automatically transferred from the transmitter to the receiver between the dots and dashes of the transmitted signals. This permits the operator to listen-in while sending. A stand-by send-receive switch is also included to be used in place of the break-in relay, if desired, or to cover long listening-in periods during which the transmitter may be shut down.

The following vacuum tubes are utilized:

	2 Kw.	4 Kw.
Kenotron rectifiers (UV-218)	2	4
Pliotron oscillators (UV-206)	3	5

The power for operation is to be supplied at 110 or 220 volts, 50 or 60 cycles, single phase, alternating current; and at full load the sets will draw approximately 8 and 12 kw. respectively from the line. Provision is made in the transmitter for compensating for normal changes in supply voltage, i.e., an increase or decrease of 10 per cent above or below normal.

Control is normally obtained by means of auxiliary equipment constructed for mounting on the operator's table. This equipment consists of a telegraph key with a back con-

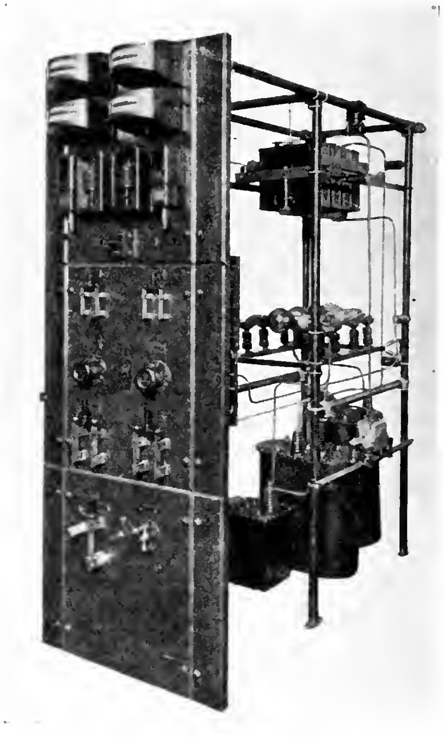


Fig. 4. Rectifier Equipment

tact for operating the break-in relay (Fig. 2) and the operator's signal and control cabinet (Fig. 3) which includes the following:

1. Stop-and-start switch, which opens and closes the main-line contactor mounted on the rectifier panel.
2. Tumbler switch for controlling the stand-by send-receive switch mounted in the antenna tuning unit structure.
3. Three indicating drops, which indicate plate overload and kenotron or pliotron filament over-voltage respectively.

Each of the three drops actuates a buzzer which indicates to the operator that the transmitter requires attention.

The controls supplied for the operator's table, while sufficient for normal operation, do not take care of all adjustments for the set. Wave change, power change, signal change, filament voltage adjustment, and line voltage compensation are controlled at the transmitter. Provision is also made for starting and stopping the set (i.e., closing and opening the main-line contactor) from push buttons located on the rectifier and oscillator panels.

The sets are provided with protective equipment which will prevent their being injured in the event they are improperly operated.

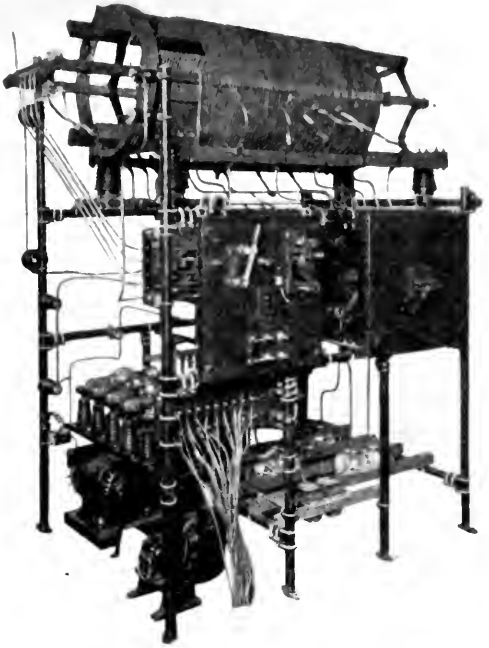


Fig. 6. Oscillator Equipment

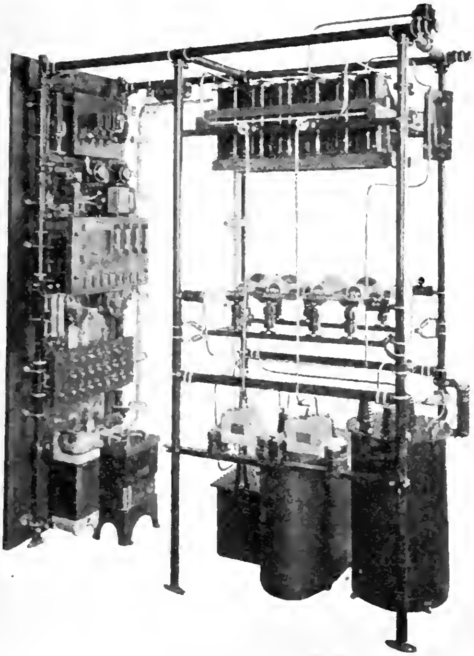


Fig. 5. Rectifier Equipment

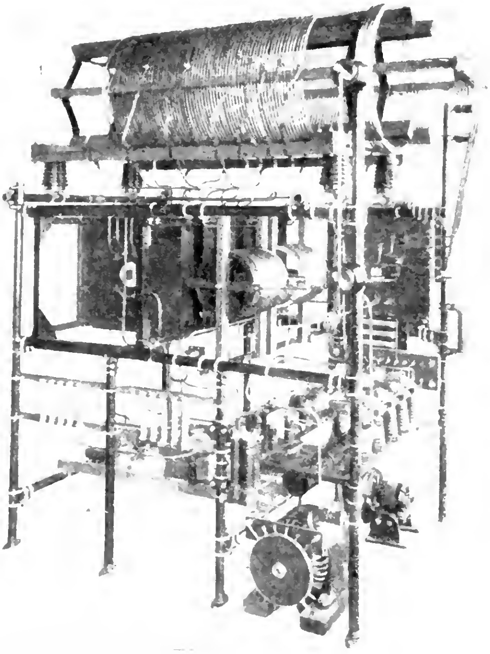


Fig. 7. Oscillator Equipment

In case of plate overload a relay actuates, opening the holding coil of the master protective relay and thus cutting all power off the set.

Protective relays in the kenotron and pliotron filament circuits actuate the drops and buzzer in the operator's signal and control cabinet. When over-voltage occurs, the set is automatically shut down. When under-voltage occurs, the relays actuate buzzers located in the rear of the rectifier panel, attracting the operator's attention to this condition.

An interlock is included in the stand-by send-receive relay, which prevents the transmitter being started when in the "Receive" position.

Switches are provided on the gates of the surrounding railing so that the set is automatically shut down when the gates are opened.

A condenser-discharge switch is included in the rectifier panel which automatically discharges the filter-system condensers when the set is shut down.

Safety gaps are included across the terminals of all condensers in the set to take care of any abnormal surges which may be developed while making initial adjustments.

The low-voltage circuits for the operation of auxiliary equipment and relays are protected against radio-frequency induction by suitable condenser systems.

All major power circuits are fused.

The transmitters consist essentially of four component circuits: a rectifying circuit, used to obtain a source of high-voltage direct current for the plate circuit of the pliotrons; a filter circuit, which smoothes out the ripple in the rectified alternating current; an oscillator circuit, which converts the high-voltage direct-current output of the rectifier and filter circuit into radio-frequency current; and a tuning circuit, by which the wavelength of the antenna circuit is adjusted to the wavelength of the transmitter. The transmitted wavelength is established primarily by the transmitter, to which the antenna is tuned. This practically eliminates any variation in the emitted wavelength due to slight changes in antenna constants.

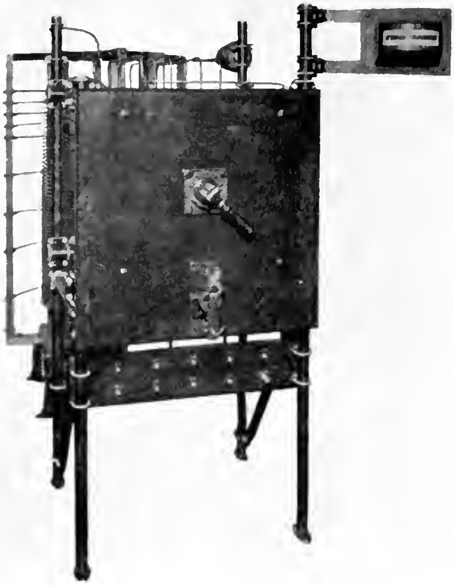


Fig. 8. Antenna Tuning Unit

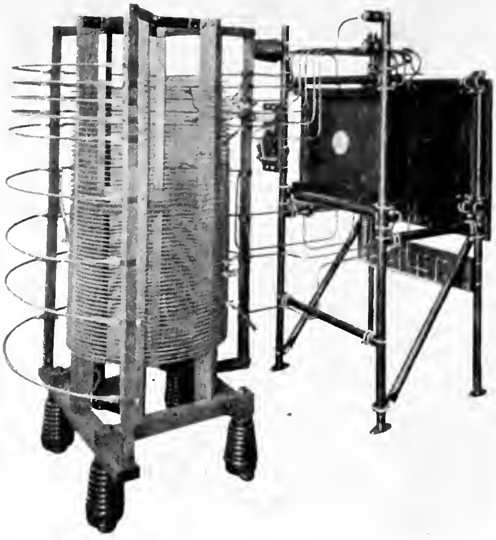


Fig. 9. Antenna Tuning Unit

The foregoing circuits are built in three independent units. A vacuum-tube rectifier panel contains the rectifying and filtering circuits; a vacuum-tube oscillator panel contains the oscillators and auxiliary circuits for converting the direct-current supply into radio-frequency power; and an antenna tuning unit contains the equipment necessary for adjusting the wavelength of the antenna.

The vacuum-tube rectifier for the 4-kw. transmitter is illustrated in Figs. 4 and 5.

The rectifiers contain the following component units in both the 2- and the 4-kw. sets:

High-voltage and filament transformers
Rectifier tubes and mountings
Isolating switches
Filter inductance and condensers
Supply-voltage compensator
Power-change switch
Filament-control rheostats
Filament voltmeter
Wattmeter
Plate-circuit ammeter
Line voltmeter
Protective relays

The wave-change switch has four bank and selects taps on the plate coil, oscillation transformer, intermediate circuit condensers and the grid coil, thereby adjusting the set for best operation on each wavelength.

The antenna tuning unit, which is the same in the 2- and 4-kw equipment, is illustrated in Figs. 8 and 9. It contains a wave-change switch, the break-in relay, an antenna loading inductance, the stand-by send-receive relay, and an antenna-current ammeter.

The weights and dimensions of the complete transmitters are given in Table I.

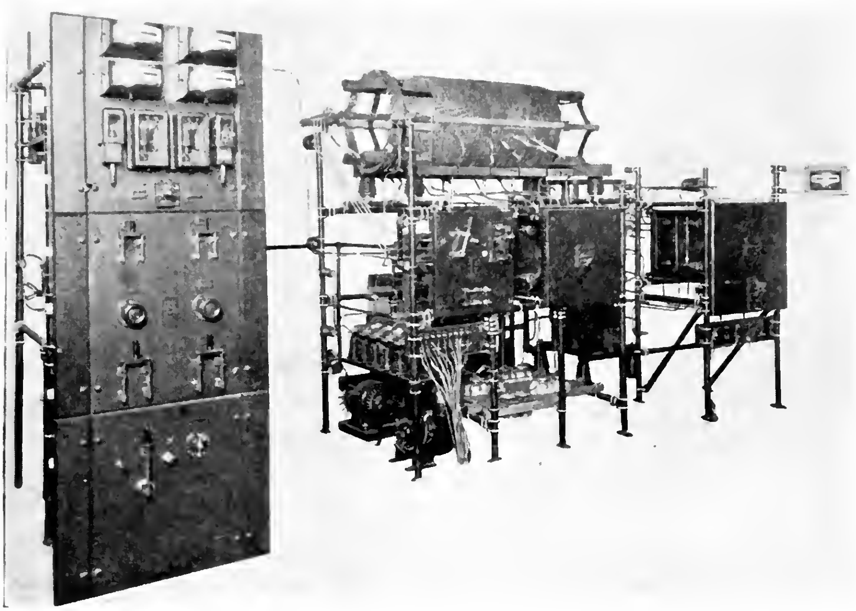


Fig. 10. Complete Assembly of the Radio Transmission Equipment for a Station

The vacuum-tube oscillator for the 4-kw. transmitter is illustrated in Figs. 6 and 7. It contains the following component units:

Pliotron oscillators
Oscillation transformer
Wave-change switch
Equipment for obtaining interrupted-continuous-wave transmission
Signal-change switch
Key relay and keying system.

The development and design of these transmitters was particularly difficult, in that the ratings were higher than those of any other transmitters built up to that time in this country, and there was very little if any standard practice to be guided by. This refers not only to the complete assembly but to a great many of the component units, such as transformers, condensers, filter systems, and the vacuum tubes themselves.

TABLE I

Units	WEIGHT	WEIGHT	DIMENSIONS IN INCHES, 2 AND 4 KW.		
	2 Kw.	4 Kw.	Height	Width	Depth
Rectifier	2400	3000	96	34	70
Oscillator	1750	2000	96	78	64
Antenna Tuning	825	825	75	50	96
Accessories	250	250			

Cast Iron Welding

The art of welding cast iron has not progressed with the same rapidity as that of welding other metals because the many and varied ingredients entering into the composition of cast iron each have a great influence upon its weldability. The enormous field for welding cast iron constitutes so great an incentive, however, that the American Bureau of Welding recently conducted an investigation to determine the proper technique. The following article reports the general considerations that were arrived at and later installments will detail the findings with respect to the use of the electric arc.—EDITOR.

GENERAL CONSIDERATION

For years it has been common practice to repair defective iron castings in the foundry, by cutting out the defect, forming a sand mold around it, and then pouring very hot melted iron into the mold and allowing it to overflow and waste, until the surface of the defect is melted, when the mold is allowed to fill, the supply of melted iron is cut off, and the casting allowed to cool. The process is called "burning in." In many cases good results are obtained, but frequently there are disadvantages of high cost, cracked castings, and the difficulty of machining the "burn" or the metal near it.

Modern methods of repairing cast iron parts are replacing the old practice, with better results in every way. There are still, however, many matters that need more study.

Field for Cast Iron Welding

The field for possible applications of cast iron welding is enormous. At present, unlike the welding of steel, the welding of cast iron is confined entirely to repair or salvage work. However, with the further perfection of methods of making strong, homogeneous, machineable welds in cast iron, at a reasonable cost, there is reason to believe that the art of welding may be employed in the fabrication of structures of cast iron, just as it is at this time used in joining cast steel sections.

But in repair work alone, cast iron welding can be extensively used and effect great savings. Consider the foundry in which the castings are manufactured; welding can be and is employed to fill up blowholes and gas holes; to build up castings that do not quite meet the required dimensions; and for various other purposes, making useful castings of what would otherwise be scrapped material, saving expense for the foundryman and delay for the purchaser of the castings.

After the castings leave the foundry and go to the machine shop, further defects, remediable by welding, may be uncovered by the machining process. Or the machinist may inadvertently remove too much metal, which can be replaced by welding. Here are other opportunities for welding to make further savings of time and money, before the casting even reaches its final destination.

Then, when the iron casting has become a part of an engine, a generator, a boring mill, a punch press, an automobile, a sewing machine, or what not, there is always the chance that some unusual strain to which the machine is subjected, a flaw in the casting, or some other cause, will effect its failure, resulting in loss of use of the machine of which it is a part until it can be replaced or repaired. In the case of large important castings, the time required for obtaining a new one may be a matter of weeks or months and the expense involved very great, especially if the loss of output from the disabled machine is considered.

Here is the great field for cast iron welding, namely, the repair of broken castings. In some cases the possibility of doing the repair without removing the broken part from its operating position alone effects a large saving in time and money. In others, it is the expense involved in scrapping the broken casting and obtaining a replacement which is the important item. In still others, time is the all important consideration. In all these cases, if a satisfactory method of welding is available, an economic saving will be effected and any process that can bring about savings of time and money to industry in general deserves earnest and thorough study and investigation in an effort to advance or perfect its use.

Iron Ore—Pig Iron—Cast Iron

Cast iron, as presented to the welder, is obtained from pig iron, which has been produced by smelting iron ore in the blast furnace. The molten iron, while in the blast furnace, comes in contact with other elements existing in the ore or fuel and takes them up to an extent depending on the amount present and the conditions under which the furnace is operated.

Some of these elements, notably carbon, silicon, sulphur, phosphorus, and manganese, are absorbed by the iron in large amounts and as these amounts vary, so do also the physical properties of the cast iron. It is quite probable that they also affect its weldability to some extent, though this needs further research. Carbon is by far the most important element and has the greatest effect, while the others are all of value at times, except sulphur which is always injurious even in small amounts.

The molten iron from the blast furnace, with its content of carbon, silicon, manganese, sulphur, and phosphorus, is cast into pigs, which are shipped to the foundrymen to be made into iron castings.

Control of Composition and Characteristics of Iron Castings

The foundryman places the pig iron, with possibly some scrap iron or steel and the necessary amount of fuel, usually coke, in a cupola and melts it. When it is in the melted state it can again change its characteristics by absorbing elements with which it comes in contact.

Thus, the foundryman can to a certain extent control the composition of the iron which he taps from the cupola by mixing pig irons and scrap which contain different proportions of these various elements and by using fuels which contain small amounts of injurious elements, such as sulphur. Fluxes are sometimes used with good effect and various elements, such as silicon or manganese, may be added by introducing ferro-alloys, containing high percentages of these materials, into the charge.

The physical properties of the iron casting may also be varied by the method of casting. Thus if a mold is so made as to chill the molten iron quickly, a large proportion of the carbon will remain in the combined state, making a very hard casting.

Influence of Impurities on the Properties of Cast Iron

Carbon appears in cast iron in two forms, namely, combined and in the free state as graphite, sometimes called graphitic carbon. When in the combined state, it is in the form of iron carbide (Fe_3 C), frequently called cementite, a chemical compound of iron and carbon. It is very hard and brittle and has little strength. When free graphite is present, it retains its own characteristics of softness and weakness.

All cast iron contains carbon, usually from 3 to 4 per cent, but the amount of this held in the combined form depends on the rate at which the casting is cooled and also on the amount of other elements, principally silicon, present in the iron. When the iron is molten, practically all the carbon is held as iron carbide. Now if the casting is allowed to cool very slowly, nearly all of the carbon will pass out of the combined state and segregate as free flakes of graphite. On the other hand, if the iron is cooled with extreme rapidity, a large proportion of the carbon will remain in the form of iron carbide.

When the carbon is in the free or graphitic state, it is mixed with the iron in the form of flakes and as neither pure iron nor graphite is hard or brittle, the result is a relatively soft metal, one which can readily be machined. However, the flakes of graphite separate the grains of iron from one another, thereby weakening the metal.

If the carbon is practically all in the combined state, the metal is very hard and brittle and difficult to machine.

Cast irons containing a considerable amount of graphitic carbon are known as gray cast irons because of the appearance of their fracture, which is grayish or blackish and coarsely crystalline. Those containing only combined carbon, and free therefore from graphitic carbon, are called white cast irons from the aspect of their fracture, which is white, brilliant, and highly metallic.

Silicon reduces the solubility of carbon in molten iron, so that pig irons of high silicon content have a low total carbon content. The most important effect of silicon from the standpoint of welding is that it increases the proportion of free to combined carbon, thereby making the metal soft and machineable. Thus, while the presence of silicon may not directly affect the weldability of cast iron, it is of great importance since its introduction in the weld has a strong softening influence. Silicon also helps to eliminate oxides, promote fluidity, and decreases shrinkage and chilling effects.

Sulphur exerts a very bad effect on cast iron and should be kept at a minimum. It tends to cause the carbon to be held in the combined state. This increases the hardness and also the shrinkage since carbon in the combined form occupies less bulk than graphite. It also renders the iron very weak, while at a red heat, unless a sufficient amount of manganese is present. Sulphur also makes the iron solidify more rapidly in cooling from a red heat, thereby often causing blowholes and shrinkage holes or cracks.

Thus sulphur tends to make the iron white, hard, and brittle. Its effects can be partially counteracted by silicon or manganese additions. Silicon will precipitate the carbon as free graphite, even if sulphur is present, while manganese will combine with the sulphur to form manganese sulphide.

Fig. 1. Gray Cast Iron etched with HNO_3 Magnified 75 dia.

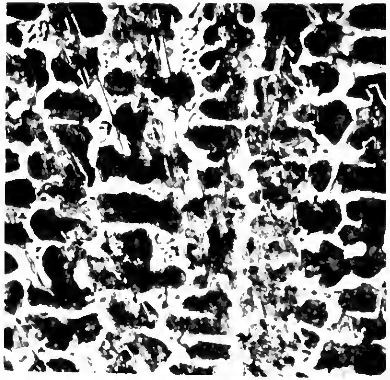


Fig. 2. White Cast Iron etched with HNO_3 Magnified 75 dia.

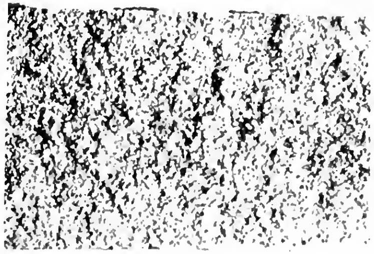


Fig. 3. Gray Cast Iron Fracture

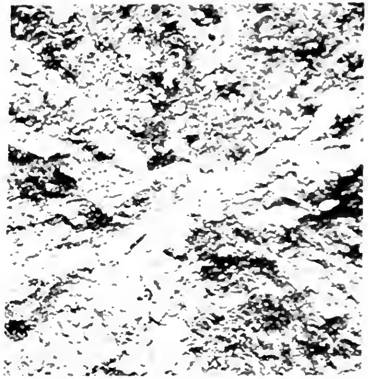


Fig. 4. White Cast Iron Fracture

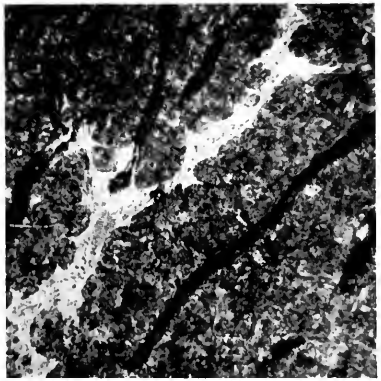


Fig. 5. Hard Close-grained Cast Iron. Matrix all pearlite. Graphite plates moderate in size. White spots phosphide eutectic. From hydraulic cylinder. Magnified 100 dia.

Fig. 6. Same as No. 5, but magnified 430 dia.

Fig. 7. Machine Cast Iron Heated Red Hot and Quenched in Ice Water. Matrix is martensite with graphite plates showing black. White spots are iron phosphide which the rapid quenching prevented from becoming phosphide eutectic. Magnified 100 dia.

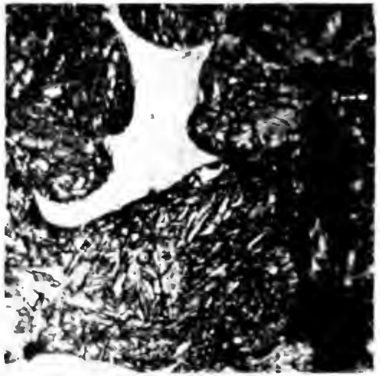


Fig. 8. Same as No. 7, but shows structure more clearly. Magnified 430 dia.

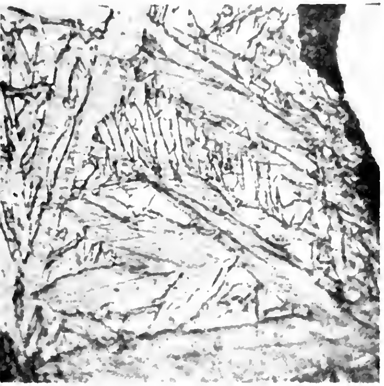


Fig. 9. Same as No. 7, but magnified 1200 dia. showing clearly the Martensite Structure of the Matrix

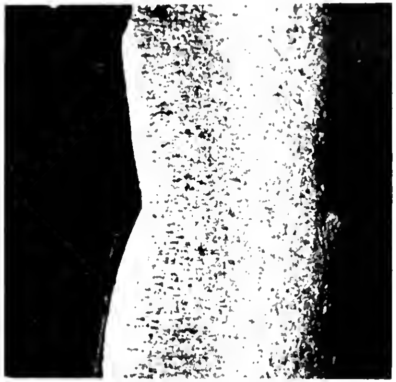


Fig. 10. Hard Spot in Cast Iron made by just melting surface with torch and allowing it to cool in air. The rapid cooling has changed it to chilled iron. Magnified 2 dia.

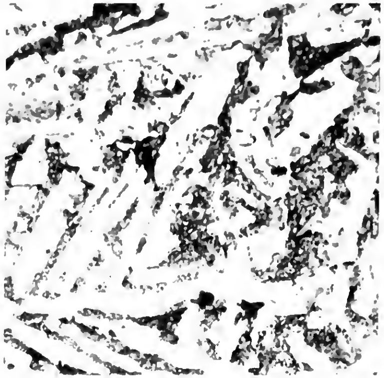


Fig. 11. Structure of Chilled Iron in Hard Spot. White is cementite, matrix pearlite with a few spots of graphite. Magnified 100 dia.

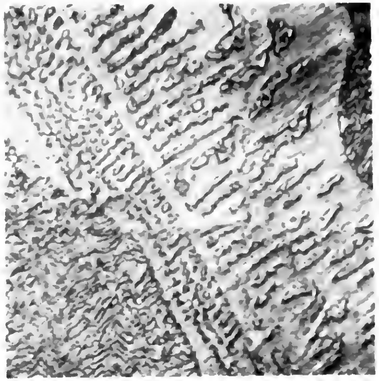


Fig. 12. Phosphide Eutectic in Cast Iron with Pearlite Fringe around it. Magnified 1200 dia.

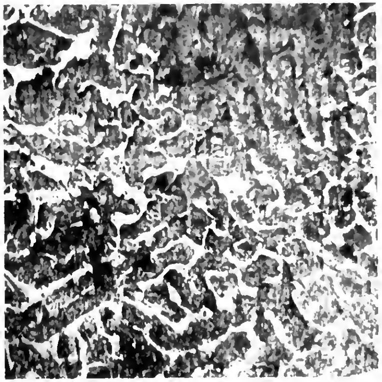


Fig. 13. Chilled Iron Casting. The White is cementite, the matrix pearlite and there is some carbon as graphite at the right. Magnified 100 dia.

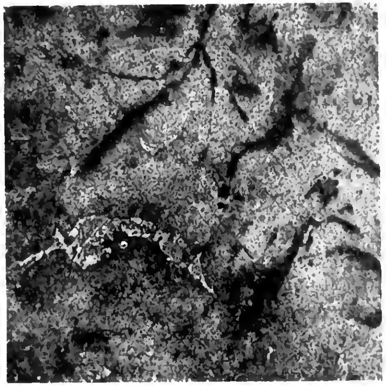


Fig. 14. Another Close-grained Cast Iron with less graphite than No. 5 and also less phosphorous. Magnified 100 dia.

Fig. 15. Good Machine Iron. Ferrite around graphite plates and rest of the matrix pearlite. Graphite plates of moderate size and number. Magnified 200 dia.

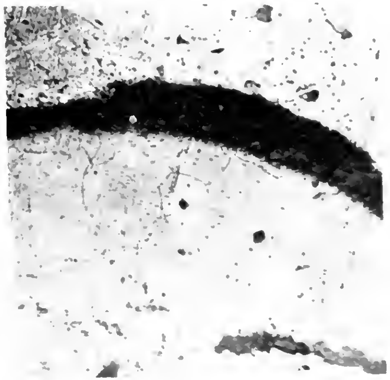


Fig. 16. Very Soft Cast Iron. No pearlite Matrix all ferrite. Graphite plates large Taken from large casting in dry sand. Magnified 200 dia.

Phosphorus lowers the melting point of cast iron and makes it hard, brittle, and weak. In the amounts ordinarily present in foundry irons, it has no effect on the ratio of combined to free carbon, but itself forms a compound with iron and iron carbide, which is hard and brittle, has a low melting point, and confers these properties on cast iron. If enough silicon is present to prevent the formation of iron carbide, the iron will be softer, but still brittle.

The amount of phosphorus is usually kept as low as possible, except in castings having very thin sections, where a very fluid iron is necessary to ensure filling all parts of the mold. In such cases, a high phosphorous iron is used because of its fluidity, in spite of its weakness and brittleness.

Manganese has several effects on cast iron. Its principal one is to combine with the sulphur, forming manganese sulphide, which occurs in small gray particles, which, unless segregated, have little effect on the strength of the casting. It also helps to deoxidize the metal. Further, it combines with some of the carbon, making (Mn_3 C) manganese carbide. This has the same properties of hardness and brittleness as iron carbide, so that while by combining with sulphur, it softens the iron, it hardens it by combining with the carbon. As neither sulphur nor manganese is uniformly distributed in the metal, it is necessary to have an excess of manganese present, to be sure that all of the sulphur is taken care of.

General

From the foregoing brief statements, it is evident that the effect of any one element on the properties of cast iron is dependent on the amount of the various other impurities present and upon the rate of cooling of the casting. The effects are in many cases much more complicated than have been indicated. A full discussion of this subject is far beyond the scope of this article.

Classes of Gray Iron Castings

Since gray iron castings are machineable and in other ways better than white iron for most purposes, the majority of castings presented to the welder will be of gray iron. For practical purposes, gray iron castings can be divided into three classes:

(1) Machinery castings.
(2) Stove plate.
(3) Specialties, such as structural castings.

Machinery castings, as the name implies, are castings which are made as strong as is compatible with having them soft enough to be machineable. It is evident that this class includes irons of widely varying composition, as the foundryman will vary the mixtures according to the size and shape of the castings which he is making as well as the use to which it is to be put. Castings of very heavy cross-section will be machineable even though they have a low silicon content. This is true because the heavy section insures a low rate of cooling and much silicon is not needed to cause the precipitation of free graphite.

TYPICAL ANALYSIS OF "GRAY" AND "WHITE" CAST IRON

	Gray. Per Cent	White. Per Cent
Total Carbon	3.30	3.20
Graphitic Carbon	2.80	(all combined)
Combined Carbon	0.40	3.20
Silicon	2.50	0.80
Manganese	0.50	0.45
Phosphorous	0.60	0.20
Sulphur	0.10	0.15

Stove Plate castings are necessarily of thin cross-section and consequently are usually made from iron containing high percentages of silicon and phosphorus. When castings, even though they be of heavy section, such as grate bars, are made in a stove plate foundry, they usually are of this same grade of iron.

Structural Castings are made for strength alone. Of course there are exceptions to this statement, such as certain columns and special shapes, which require machining. A casting from a specialty shop, or a structural casting, will use a high percentage of combined carbon.

In Figs. 1, 2, 3, and 4 are illustrated the two extremes, a gray iron in which practically all of the carbon is in the free state, and a white iron in which almost all of the carbon is in the combined form. The greater the proportion of free or graphitic carbon, the darker will be the appearance of the fracture and the grain will be coarser and more open, showing large crystals of iron with intervening flakes of graphite. Filings from such an iron will soil the hands or mark on paper, owing to the presence of the graphite. On the other hand, the fracture of the white iron is light in color and brilliant, and is close grained, with small crystals. Thus, from the appearance of the fracture, it is possible to estimate the proportion of free to combined carbon and thus determine in a measure the characteristics of the iron to be welded.

Factors Affecting Cast Iron Welds

Carbon

In making a weld in commercial cast iron, the surfaces which are to be joined must again be melted. These surfaces consist of iron which contains carbon in both the free and combined states. When these surfaces are melted, several things happen. First, both the graphitic and combined carbon go into solution in the molten metal. Second, some of the carbon, silicon, and manganese are burned out by the heat, while the amounts of sulphur and phosphorus are practically unchanged. Silicon is most easily burned out, so the tendency is to produce a cast iron, in the weld, that will be white when cold, owing to its low silicon and carbon content. Third, the surface of the molten metal oxidizes, making a slag which in a measure prevents further oxidation.

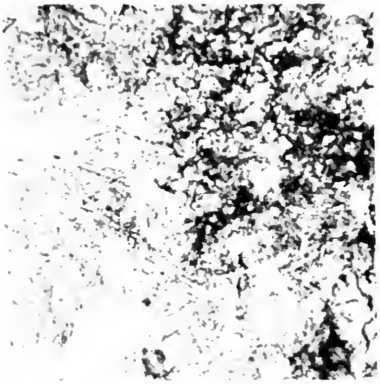


Fig. 17. Cast Iron Gas Welding Rod Heated Bright Red and Quenched in Ice Water. The structure is martensite, but there is enough silicon present to keep some carbon in the form of graphite

As soon as the welding heat is removed, the melted iron solidifies very quickly, owing to its proximity to the comparatively cold mass from which it has been melted and to its being exposed freely to the air. This sudden cooling causes a large amount of the carbon to be retained in the combined state, resulting in a white, hard, metal in the weld. Of course if the casting has been preheated before welding, the cooling of the added metal will not be so sudden and a softer machineable weld may be secured.

Experience has shown that the grade of cast iron which is most difficult to weld successfully is that which is soft and has an open grain. However, little difficulty is encountered when the metal is of comparatively thin (one-half inch or less) section.

Oxidation

When iron is molten, or even red-hot, it oxidizes very readily if exposed to the air. Thus in welding, the surface of the molten metal becomes covered with iron oxide, which may be deposited in the weld by mixing with the molten metal, or by being trapped between two layers of metal added at different times. In either case, the result will be a weak, non-homogeneous weld for the oxide particles segregate and do not form a junction with the adjacent metal.

Shape of Casting

The shape of castings must also be taken into consideration. A casting comprising both light and heavy parts is subjected to more internal stresses than one of homogeneous cross-sections. These stresses are caused by the different rates of cooling, light sections cooling more rapidly than heavy. There are also internal stresses set up at sharp angles.

Shrinkage

When in the welding of cast iron, a filler metal of different composition than that of the casting is used, serious consideration must be given to the fact that the co-efficient of expansion and consequently the shrinkage of the metal in the weld may be different than that of the remainder of the casting.

The different shrinkages of the two metals will tend to cause one to slide on the other as they pass from the liquid to the solid state. This shrinkage of course sets up internal strains which the ductility of the welding material must take care of. Altering the carbon content from the combined to the graphitic state helps decrease the shrinkage. If the iron contains a weakening agent the internal strains set up by shrinkage often cause cracks to appear.

Summary

From the foregoing, it is evident that the term cast iron is applied to metal of widely varying composition and characteristics. Cast iron always contains in the neighborhood of 3 per cent of carbon, but this may be in either the combined or graphitic state and it may hold widely varying amounts of other elements, as silicon, manganese, sulphur, and phosphorus. Not only the presence of these elements, but also the rate of cooling of the casting, profoundly affect the physical characteristics and weldability of the metal.

Electrification of the Mexican Railway

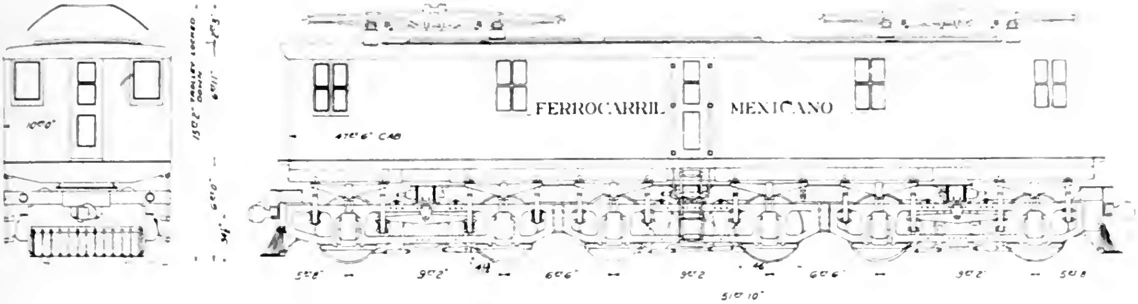
The Mexican Railway Company, Ltd., is the most recent convert to electrification and has selected the difficult Orizaba Division for the initial installation. Not only is the capacity of the system limited by the capabilities of the present steam equipment, but the operating costs are so high that savings by electrification are expected to pay for the change-over in five or six years of normal traffic.—EDITOR.

One of the most interesting electrifications yet undertaken has been initiated by the Mexican Railway Company, Ltd., on the single-track line between Mexico City and Vera Cruz. This line, which is 264 miles in length (exclusive of branch lines), was at the time of its construction one of the most difficult engineering problems ever carried through. At its maximum elevation the road reaches an altitude of 8323 ft. above sea level. It is significant that for electrification the initial section between Esperanza and Orizaba has been chosen, which is by far the most difficult division due to heavy curvatures and grades reaching 4.7 per cent ruling and a maximum of 5.25 per cent.

Passenger Train on Mexican Railway Hauled by Two Double-ended Steam Locomotives Ascending 4½ Per Cent Grade North of La Bota

This section of the road locally called the Maltrata Incline traverses a remarkably scenic country passing under the shadow of Orizaba Peak, which is one of several extinct volcanoes in the immediate vicinity ranging in height from 17,000 to 18,000 ft. The contract received by the International General Electric Company covers the electrification of 30 miles of single track, at an estimated cost of between $2,000,000 and $2,500,000. This is the first main line electrification to be installed in Mexico and the first heavy steam road electrification to be initiated in North America since the world war. By changing from steam to electric haulage it is expected that the necessity for double tracking the road will be indefinitely postponed, and that the saving in the operation of the system will be sufficient to repay the entire cost of electrification within five or six years.

The equipment ordered includes ten 150-ton articulated-type locomotives, which will be used interchangeably for freight and passenger service, and trolley overhead and feeder lines complete for the direct-current supply. Power will be supplied by the Pueblo Tram-

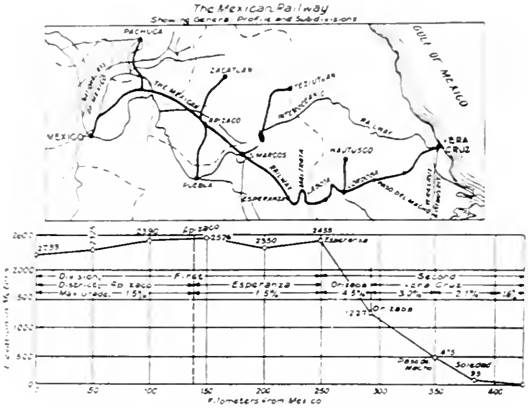


Outline and Dimensions of 150-ton 3000-volt Type of Locomotive for the Mexican Railway Company, Ltd.

way Light and Power Co. whose plant is located about five miles from the City of Orizaba. A single substation containing two 3000-kw. synchronous-motor-generator sets will supply power to the entire 30 miles.

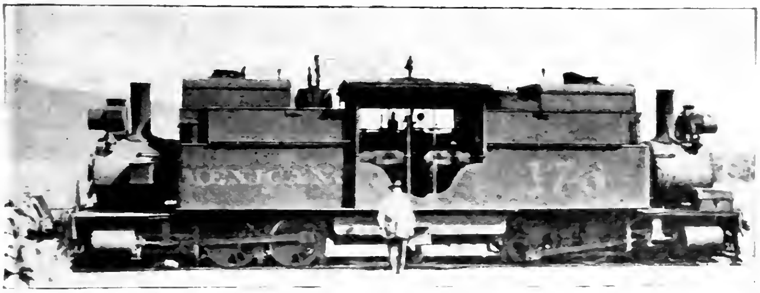
The locomotives are of particular interest since they will replace double-ended oil-burning steam locomotives, each carrying six driving axles without idle trucks. These steam locomotives are furthermore capable of operating with equal facility in either direction. The electric locomotives will also have six driving axles contained in three double trucks, each equipped with two 1500/3000-volt motors. These motors will be twin geared to the driving wheels and are similar in general to the articulated truck design now operating through the Detroit Tunnel and on the Baltimore and Ohio; Butte, Anaconda and Pacific; and the Chicago, Milwaukee and St. Paul Railways. The three-truck construction with one cab, however, is new and makes possible a single unit of 150 tons adhesive weight without exceeding 50,000 lb. per axle. The contract provides for three running speeds with an additional arrangement for shunting the fields on light grades or with light trains. Full regenerative control will be provided and the locomotives will be capable of either independent or multiple-unit operation.

In addition to the remarkable mountain scenery, the Mexican Railway passes through a country of unusual historic interest. Between the height of land and the City of Mexico, the little known American pyramids may be seen



Map and Profile of Mexican Railway Between Mexico City and Vera Cruz

and other relics of the former inhabitants of this country. In the fertile Orizaba section, which has a semi-tropical climate, may be found growing wild oranges, bananas, grape fruit, coffee, and other tropical vegetation.



150-ton Oil-burning Double-ended Type of Steam Engine Now Used on the Crizaba Section, Mexican Railway

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted, which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Arc Welding

Electric Arc Welding Apparatus and Equipment. Caldwell, J.
Elec'n, Dec. 22, 1922; v. 89, pp. 711-712, 713.
(Abstract of a paper read before the Institution of Electrical Engineers.)

Carrier-current Communication

How "Wired Wireless" Works. Mauborgne, J. A.
Tel. Engr., Dec., 1922; v. 26, pp. 19-23.
(Includes bibliography of nine entries.)

Telephony Over Power Lines in Europe. Anderson, Clifford N.
Elec. Wld., Jan. 6, 1923; v. 81, pp. 45-46.
(Short article on methods used.)

Corrosion

Corrosion as Affecting the Metals Used in the Mechanical Arts. Hatfield, W. H.
Engr., Dec. 15, 1922; v. 134, pp. 639-643.
(Gives results of extensive tests.)

Current-collecting Devices

New Non-Fouling Trolley Shoe Given Test on London Tramway.
Elec. Trac., Dec., 1922; v. 18, pp. 1061-1062.
(Short description including test results.)

Dielectric Strength

Physical Nature of the Electrical Breakdown of Solid Dielectrics. Wagner, Karl Willy.
A.I.E.E. Jour., Dec., 1922; v. 41,.pp. 1034-1044.

Electric Distribution

Factors in Industrial Plant Distribution. Stevens, Roger B.
Elec. Wld., Dec. 9, 1922; v. 80, pp. 1259-1262.

Electric Drive—Steel Mills

Improved Rolling Mill Practice Obtained by the Use of Direct Current Motors for Main Roll Drive. Stoltz, G. E.
Assoc. Ir. & St. Elec. Engrs., Dec., 1922; v. 4, pp. 777-799.
(Discusses certain principles of steel mill electric drive.)

Electric Locomotives

Power Characteristics of the Electric Locomotive. Wichert, A. (In German.)
Zeit. des Ver. Deut. Ing., Dec. 2, 1922; v. 66, pp. 1080-1085.
(Compares operating curves of the electric locomotive and the steam locomotive. Shows that these must be considered from different viewpoints.)

Electric Measurements

Use of Condenser-Type Bushings for Measurement Purposes. Keinath, Gg. (In German.)
Siemens-Zeit., Nov., 1922; v. 2, pp. 606-614.
(Illustrated description of the applications of "Repelit" bushings for high-voltage measurements, etc., in power plants.)

Electric Meters

Photographic Method of Meter Reading Prevents Disputes with Customers.
Elec. News, Dec. 15, 1922; v. 31, p. 39.
(Special camera photographs each meter face.)

Electric Motors

Neutralized Series Conduction Motor on A-C. and D-C. Circuits. Fynn, Val. A.
A.I.E.E. Jour., Dec., 1922; v. 41, pp. 915-923.
(On the theory of operation of small and fractional horse-power motors on either a-c. or d-c.)

Electric Motors, Induction

Determining the Performance of an Induction Motor without Plotting a Circle Diagram. Smith, G. T.
Elec. Jour., Dec., 1922; v. 19, pp. 485-489.

Torque Components Due to Space Harmonics in Induction Motors. Hansen, K. L.
A.I.E.E. Jour., Dec., 1922; v. 41, pp. 928-932.
(Theoretical.)

Electric Transformers, Instrument Type

Instrument Transformers for Power Circuits—I. Gibbs, J. B.
Power Pl. Engng., Jan. 1, 1923; v. 27, pp. 86-88.
(Principles of construction and operation. Serial.)

Electric Transmission Lines

Possibilities of Transmission by Underground Cables at 100,000-150,000 V. Taylor, A. M.
Elec'n, Dec. 15, 1922; v. 89, pp. 683-684.
(Abstract of paper before the Institution of Electrical Engineers.)

Electrical Machinery—Temperature

Relation of Overload to the Inner Temperature of Machines. Semenza, Guido.
A.I.E.E. Jour., Dec., 1922; v. 41, pp. 1031-1033.

Some Development in Insulating Materials and Processes in Great Britain with Special Reference to Thermal Consideration. Fleming, A. P. M.
A.I.E.E. Jour. Dec., 1922; v. 41, pp. 924-928.

Engineering Ethics

A.S.M.E. Adopts Ethics Code.
Power, Dec. 26, 1922; v. 56, pp. 1039-1040.
(Gives full text of a code prepared by a joint committee of the national engineering societies. Intended ultimately to apply to the entire engineering profession.)

Excess Voltage

Over-Voltage Problem. Schrottke, F. (In German.)
Elek. Zeit., Nov. 30, 1922; v. 43, pp. 1425-1429.
(Report of experiences of the Siemens-Schuckert Works in the operation of over-voltage protective devices.)

Fatigue of Metals

Fatigue in Metals. Jenkin, C. F.
Engr., Dec. 8, 1922; v. 134, pp. 612-614.
(Paper before the Royal Aeronautical Society. Gives test results.)

Flywheels

Electric Mine Hoist with Ward Leonard Control and Ilgner Balancing System, Hacault, G. (In French.)
Revue Gén. de l'Elec., Dec. 2, 1922; v. 12, pp. 835-841.
(Mathematical. Serial.)

Gears

Epicyclic Reversing Gear for Ljungström Marine Turbines.
Engng., Dec. 8, 1922; v. 114, pp. 699-703.
(Illustrated description of the construction of gears manufactured by the Ljungström Turbine Works, Sweden.)

Hydroelectric Development

Electric Plant Built on a Dam. (In French.)
Génie Civil, Dec. 9, 1922; v. 81, pp. 529-532.
(Illustrated description of the dam and plant built on the Leguer River, near Belle-Isle-en-Terre, France.)

Industries, Electrical

André-Marie Ampère. (In French.)
Revue Gén. de l'Elec., Special number. Nov., 1922; v. 6, pp. 1-306.
(Life and works of Ampère, together with a number of articles on the present state of the French electrical industry in all its phases.)

Insulating Oils

On the Use of Oil for Transformers. Mercier, H. (In French.)
Revue Gén. de l'Elec., Dec. 2, 1922; v. 12, pp. 858-860.
(Gives hints for maintenance and precautions to be taken in handling transformer oils. Serial.)

Insulation

Influence of Temperature on Insulating Materials Used in Electrical Machinery. Vannotti, Ernesto.
A.I.E.E. Jour., Dec., 1922; v. 41, pp. 933-934.

Insulators

Pin Insulators on 90,000-Volt Line. Ackerman, Paul.
Elec. Wld., Dec. 30, 1922; v. 80, pp. 1439-1444.
(Experiences of the Toronto Power Company.)

Insulators—Testing

Contribution to the Study of Insulator Chain for High Tension Systems. Viel, G. (In French.)
Revue Gén. de l'Elec., Nov. 25, 1922; v. 12, pp. 801-803.
(Short article supplementing the author's previous paper in the issue of February 25, 1922, p. 273.)

Lightning Protection

Disturbances in Electrical Plants Due to Lightning.
Brown Boveri Rev., Nov., 1922; v. 9, pp. 234-239.
("Statistical data, practical conclusions, theories propounded and typical examples." Serial.)

Machinery—Foundations

Erecting Power Machinery Having Cast-Iron Bedplates. Rea, N. L.
Power, Dec. 26, 1922; v. 56, pp. 1021-1023.
(Presents practical methods.)

Lubrication and Lubricants—Testing

Some Recent Researches on Lubrication. Stanton, T. E.
Engr., Dec. 8, 1922; v. 134, pp. 598-600.
(Abstract of a paper before the Institution of Mechanical Engineers. On methods of testing.)

Measuring Instruments

Elverson Oscilloscope.
Engng., Dec. 8, 1922; v. 114, pp. 720-722.
(Describes the construction and use of a device by means of which a rapidly moving mechanism may be made to appear slowed down or stopped.)

Oscillographs

Oscillograph and Some of Its Practical Applications. Borden, Perry A.
Bul. of Hyd. Pr. Comm. of Ont., Nov., 1922; v. 9, pp. 339-347.

Poles, Concrete

Method of Building Reinforced Concrete Poles. Maréchal, E. (In French.)
Revue Gén. de l'Elec., Dec. 23, 1922; v. 12, pp. 989-992.
(Gives design of a pole which could be manufactured in the factory on a quantity production basis.)

Power Costs

Cost of Power Per $100 of Pay-Roll. Walker, P. F.
Man. Engng., Dec., 1922; v. 3, pp. 339-342.
(On the subject of power costs in manufacturing plants.

Power Factor

Methods for Correcting Power Factor. Hubert, E. H.
Ind. Engr., Dec., 1922; v. 80, pp. 561-567, 605-606.
(On practical methods of power-factor correction and on the economic advantages to be derived.

Radio Communication

Radiophone Insures Service to Customers. Pearson, E. F.
Elec. Wld., Dec. 23, 1922; v. 80, pp. 1395-1396.
(Illustrates and describes equipment installed in the Portland, Oregon, offices of the Northwestern Electric Company.)

Scientific Management

Management. A Review of Ten Years' Progress. Alford, L. P.
Man. Engng., Nov., 1922; v. 3, pp. 277-282.

Statistics—Electric Furnaces

Electric Steel Industry After Ten Years. Cone, Edwin F.
Iron Age, Jan. 4, 1923; v. 111, pp. 80-83.
(Consists essentially of tables of electric furnace installations in the United States and Canada.)

Steam Boilers

Investigation and Discussion of Slag Formation on Boiler Tubes. Bates, Harry H.
Blast Fur. & St. Pl., Dec., 1922; v. 10, pp. 642-646.
(Gives results of tests.)

Steam Boilers—Testing

Tests of a large Type W Stirling Boiler. Thompson, Paul W.
Mech. Engng., Jan., 1923; v. 45, pp. 25-31, 44.
(Results of extensive tests conducted by the Detroit Edison Company.)

Steam Plants

Steam Engineering Practice in Modern Central Stations. Keating, T. E.
Elec. Jour., Dec., 1922; v. 19, pp. 490-496.

Steam Turbines

Check on Steam-Turbine Performance. Phillips, H. M.
Power, Dec. 26, 1922; v. 56, pp. 1012-1014.
("The nozzle or inlet pressure used to determine relative efficiency, total steam per hour, and power output.")

Dividing Load Between Units. Davison, George R.
Elec. Wld., Dec. 23, 1922; v. 80, pp. 1385-1387.
(Methods of operation of steam turbines.)

Stokers

Developments in Stoker Practice.
Mech. Engng., Jan., 1923; v. 45, pp. 14-24.
(A group of three articles by Marsh, Bouton, and Lawrence.)

Switches and Switchgear

Enclosed Switches. Jennings, O. S.
Elec. Jour., Dec., 1922; v. 19, pp. 496-498.
(General considerations as to design and construction.)

Safety Switches. Vanderwaart, P. T.
Assoc. Ir. & St. Elec. Engrs., Dec., 1922; v. 4, pp. 801-819.
(Discusses the fundamentals of electric safety switch practice.)

Vibrations

Torsional Oscillations in Propeller Shafts. Thorne, A. T. and Calderwood, J.
Engng., Dec. 29, 1922; v. 114, pp. 815-818.
("Notes on torsional oscillations with special reference to marine reduction gearing.")

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Berechnen und Entwerfen von Turbinen und Wasserkraft-anlagen. Ed. 3. Holl. 181 pp., 1922, München, R. Oldenbourg.

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Diesel Engines for Land and Marine Work. Ed. 5. A. P. Chalkley. 330 pp., 1922, N. Y., D. Van Nostrand Co.

Direct-current Machinery. Harold Pender. 314 pp., 1922, N. Y., John Wiley & Sons.

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Handbook for Electrical Engineers. Ed. 2. Harold Pender and W. A. Del Mar. 2263 pp., 1922, N. Y., John Wiley & Sons.

Measurement of Gas and Liquids by Orifice Meter. Ed. 2. Henry P. Westcott and J. C. Diehl. 434 pp., 1922, Erie, Pa., Metric Metal Works.

Mechanical Handling and Storing of Material. Ed. 3. George Frederick Zimmer. 804 pp., 1922, N. Y., D. Van Nostrand Co.

Production Engineering and Cost Keeping for Machine Shops. William R. Basset and Johnson Heywood. 311 pp., 1922, McGraw-Hill Book Co., Inc.

Steam-engine Principles and Practice. Terrell Croft, Editor. 513 pp., 1922, N. Y., McGraw-Hill Book Co., Inc.

Steam Turbine; Theory and Practice. William J. Kearton. 456 pp., 1922, N. Y., Sir Isaac Pitman & Sons.

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Theory of Wave Transmission. Ed. 2, rev. George Constantinesco. 209 pp., 1922, Lond., Walter Haddon.

GENERAL ELECTRIC REVIEW

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Vol. XXVI, No. 4 APRIL, 1923

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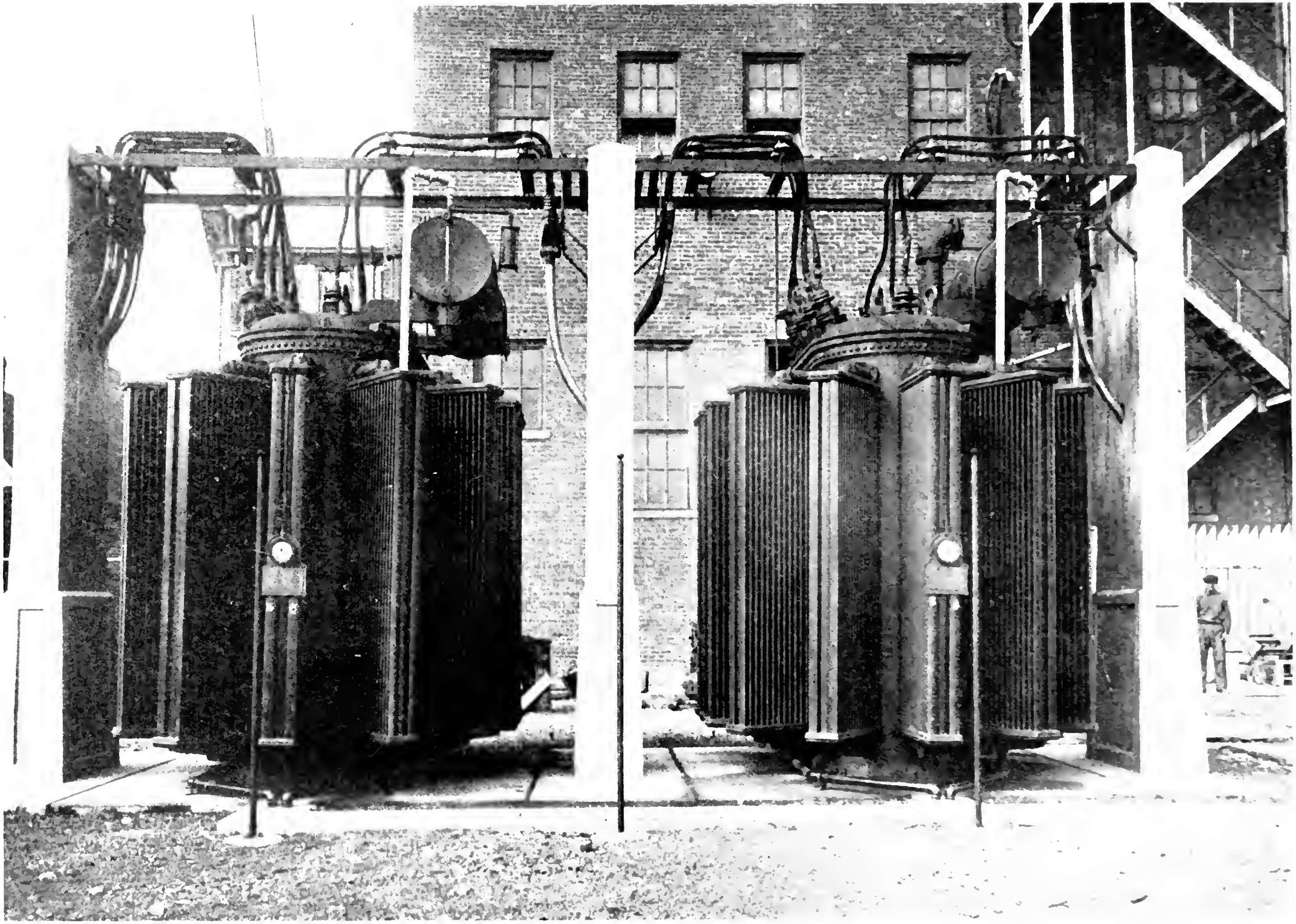


Installation of 7500-kv-a. Three-phase Transformers with Conservators, New York and Queens Electric Light and Power Co.
An outline of the development of the conservator-type transformer appears on page 228 of this issue

GENERAL ELECTRIC REVIEW

THIRTY CENTURIES

It should be of interest to the electrical industry that the rays from a 2000-candlepower ½-watt incandescent lamp were the first to shed light in the tomb of Tutankhamen after a darkness of more than 3000 years.

Tutankhamen, with the treasures we are all admiring so much at the moment, was buried several centuries before Thales of Miletus discovered electricity, but it was just about 2500 years after Thales discovered electricity that man made the first incandescent lamp.

Such *was* the speed of our development.

After the drawn wire tungsten lamp was developed in the Research Laboratory at Schenectady, in a single decade this lamp had become practically speaking the universal standard of the world.

Such *is* the speed of our development.

* * *

Three thousand years seems like a very long time—yet man sometimes lives to the age of 100 years—so it is just the span of thirty old men's lives.

* * *

Tutankhamen's chariots should be of interest to the modern engineer—we wonder what the distance between wheels is—how far from 4 feet 8½ inches?

Two years hence—in 1925—we shall celebrate the one hundredth anniversary of the opening of the Stockton and Darlington railroad. From Tutankhamen's chariot to the stage coach of 1825 represents man's progress in passenger transportation for twenty-nine centuries. From Puffing Billy to the giant "steam horses" that haul our modern passenger trains, at 70 miles an hour, represents man's progress in passenger transportation in the last century. To this thought must be added the progress made from the sailing vessel to the floating palaces of today, and again, the dirigibles and heavier than air machines that have flown across the Atlantic. These are only the products of the last few years.

There are few men who really realize the slope of the curve of our modern progress and when one does realize it, they are likely to think with McAndrew, "Leaves me no doot for the machine; but what about the man."

* * *

In talking of transportation, we wish to draw attention to Mr. W. B. Potter's article published in this issue. Mr. Potter, the Chief Engineer of the Railway Department of the General Electric Company, spent several months in Europe studying traction conditions and we believe that his remarks will be both useful and interesting to a large number of engineers on both sides of the Atlantic.

It is pleasing to find a paper on this subject that does not criticise all that is different from home practice but that rather recognizes that the traction facilities of America and the different European countries have developed to suit the conditions of the individual country and that each has peculiar characteristics and merits of its own.

* * *

As we started this editorial with thirty centuries ago in mind, it is rather interesting to invite our readers to speculate on what our transportation will have developed into thirty centuries hence. If aviation shows the same rate of development that so many of our modern marvels have—then time, distance and oceans will have been conquered by the engineer to the point where the world should be *in reality* one large family and the misunderstandings between nations should disappear. In spite of our modern pace, we can not go backward, we must go forward and the making of our future civilization is one gigantic engineering problem. Fortunately, however small the part may be, we can all play a part in this development. J. R. H.

RADIO BROADCASTING

Until the introduction of radio broadcasting, nearly all electrical inventions have been accepted slowly by the public. The incandescent lamp was invented by Edison in 1879, but today only one-third of the dwelling houses in the United States are wired for electric lighting. Water powers, which through electricity may be advantageously utilized with a great resultant saving in our coal resources, have not been thoroughly developed. The superiority of the electric locomotive to the steam locomotive has been demonstrated by years of actual service, but the general adoption of electricity for motive power by our railroads has only just begun. The same conservatism has been shown with regard to nearly every new electrical development except radio broadcasting.

The rate at which this new invention is being grasped by the public is indicated by the number of radio receiving sets being installed. Two years ago there were not more than 50,000 receiving sets in use; today the number probably exceeds one million. In the same time the number of broadcasting stations has increased from ten or twelve to more than six hundred.

The explanation of this unique public interest in a new invention is not found solely in the simplicity of radio reception, although the fact that radio programs are available anywhere to anyone who will buy a receiving set or buy the parts and put one together has much to do with the popularity of radio. However, the really important consideration is that radio broadcasting has presented us with an entirely new form of publicity which immediately takes its place with the telephone, telegraph, post office, press, pulpit, school, and theater. It is the only means of communicating instantly and simultaneously with large masses of population. One-half of the population of the United States is within the range of the Schenectady station designated by the call letters "WGY," and under favorable circumstances even greater areas are included. On last Christmas Eve a message of greeting from Vice President Calvin Coolidge, broadcast from this station, was received in every state in the Union and at Wailuku, Hawaii, Porto Rico, Liverpool, Puerta Plata, San Domingo, etc.

The newness of radio broadcasting entitles it to charitable consideration. It must be given time to develop and outgrow its youthful awkwardness. Undue regulation at this time may retard its useful growth and thwart its full development.

Radio must already be credited with many beneficial contributions to the world's prosperity and happiness. It has saved many lives in peril at sea; it provides regular and reliable trans-oceanic communication; through broadcasting it furnishes music, entertainment, education, and news to hundreds of thousands of homes, and it shortens the tedious hours for invalids and the aged in homes and the injured and sick in hospitals. The daily weather and market reports are invaluable to the great agricultural population, and the evening programs bring music and entertainment to even the most remote districts. When roads are impassable the agriculturist may still keep in touch with the commercial world, and his family can have church services, good music, educational addresses, and a variety of entertainment.

In considering the future of radio, we do not need to draw heavily upon imagination because radio has already shown that fact is stranger than fiction. It seems evident that radio will not supersede other methods of communication and publicity but will supplement them. The great field of broadcasting is the dissemination of messages and entertainment to large masses of population and this suggests two classes of stations: A few high-power stations for broadcasting matter of national importance, and a larger number of smaller stations for the broadcasting of local matter. The President of the United States might address the entire population through a high-power station or through several such stations tied together by telephone lines; the Governor of the State of New York might address the people of that State through a local station. An analogy is found in national magazines for country-wide circulation and in local papers and publications of special interest to certain localities.

It also seems evident that a variety of programs must be simultaneously available. A thousand individuals would not care to read any paper or magazine column by column in exactly the same order and at the same time, and it is unreasonable to suppose that the tens of thousands constituting radio audiences all want just one identical program. Therefore, a variety of wavelengths should be available so that listeners may have a choice of national news, local news, market and stock reports, concert music, dance music, educational matter, church services, and theatrical productions.

While fancy plays with these alluring thoughts, it is hoped that the power to speak so that thousands or even millions may hear will give rise to a desire to say something worth while and to say it well. Radio broadcasting carries with it a responsibility.

Developed along these lines with the sincere aim to present the best of everything to all the people, radio will have a powerful influence on the press, the pulpit, the school, and the theater. Public taste will be educated and it will demand higher standards. There will be a beneficial evolution of press, pulpit, school, and theater in which the inferior and the mediocre will be eliminated.

Senator Guglielmo Marconi, who has contributed so much to the history of radio, visited Schenectady last summer and spoke to the American people at the broadcasting station widely known as "WGY." His generous appreciation of the progress made in this country and his firm faith in the future of radio are expressed in his address, here quoted in full:

> "Of all the embarassing things that may happen to one in this world, one of the worst I know of is to be called upon at very short, or practically no notice, to speak to persons, or as I am in America, I think I should say, to friends, whom I cannot see, and in respect to whom one does not even know how far off or how near they may happen to be located. Assuming, however, that you would like me to speak quite naturally, and as I really feel, I wish to say how very glad I am to be here again amongst the charming, hospitable and appreciative people of this great country, America, whom I have always so sincerely admired and loved.

"Today, I have had the privilege of visiting the Works of the General Electric Company and have been truly amazed at the progress made by this great organization since the time of my last visit to Schenectady during the war five years ago. Speaking to persons interested in radio I can truly say that the practical application and study of all branches of this new method of communication is being vigorously investigated by the engineers and scientists of the General Electric Company.

"I am now convinced more than ever that our friends of the General Electric Company are great pioneers, not only in science and engineering applied to industry, but also in numerous branches of other sciences.

"No remarks of mine are necessary to tell you about what is now being done by radio, for in America you already know so much about it yourselves, but I think that broadcasting has come to stay.

"In thousands of homes in this country there are radio telephonic receivers and thousands of intelligent people, young and old, men and women, well able to use them, often able to make them, and in many cases contributing, or striving to contribute, valuable information concerning the problems still unsolved.

"But radio is destined to improve for we are still a long, long way from any kind of finality in this fascinating art. But I think I am safe in saying that if radio has already done so much for the safety of life at sea, for commerce and for commercial and military communication, it is also destined to bring new and, until recently, unforeseen opportunities for healthy recreation and instruction into the lives of millions of human beings."

M. P. Rice.

Radio Broadcasting Station WGY

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y.

By W. R. G. Baker

Radio Engineering Department, General Electric Company

WGY needs no introduction to many of our readers. During the twelve months of its operation some 50,000 letters have been received from its listeners-in scattered across one-third the circumference of the globe. These, together with the public interest which the opening of this broadcasting station aroused and the anticipation with which its daily programs are awaited, all indicate that a semi-technical semi-popular description of the station would be appreciated. The following article was prepared for this purpose at our request. The comprehensiveness of its description and the many illustrations furnish a clear understanding of Broadcasting Station WGY and its engineering operation.—Editor.

A radio telephone broadcasting station is in many respects similar to a power station. In the power system the energy of waterfalls or fuel is converted into electrical energy by means of electric generators driven by waterwheels or turbines. As shown in Fig. 1, this energy is then carried at a relatively high voltage over transmission lines to a group of power users, presumably a city. A substation located near the city steps down the voltage to a value suitable for distribution by the feeder system. Additional transformers connected to the feeder system step down the voltage to that still lower value at which it is suitable to supply the consumer with light, heat, and power.

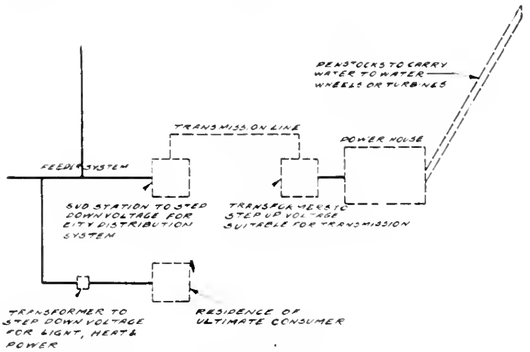


Fig. 1. Diagrammatic Illustration of a Power Distributing System

In a radio telephone broadcasting system, Fig. 2, the efforts of the artist, band, or orchestra, are converted into electrical energy. Compared with the waterfalls, this energy is of course infinitesimal. In the case of the power system the energy obtained from the waterfalls is converted into a form suitable for transmission. This also occurs at the broadcasting station with the one important exception that the energy to be broadcast is increased as it is transformed or amplified. After sufficient amplification (or increase of energy) a final transformation occurs which converts the energy into a form suitable for distribution without the use of metallic conductors. The energy is then introduced into the non-metallic distribution system where it is beyond the control of the broadcasting station and becomes available to every consumer having equipment suitable for its reception. Herein lies the very important difference between the power system and the radio telephone broadcasting system.

We may therefore state that the fundamental function of any radio telephone broadcasting station is to convert the efforts of the artists into electrical energy and to broadcast this energy so that it may be picked up by receiving stations within the range of the transmitting station.

As might be expected there are many different types of radio telephone transmitting equipments. Roughly, we may divide them into two classes: commercial and broadcasting transmitters.

Radio telephone broadcasting transmitters differ in many respects from the commercial type of radio telephone equipment. The general requirements of radio telephone transmitters, used for purposes other than broadcasting, are ordinarily determined by commercial traffic conditions. In this case, the limits of both the electrical and mechanical design are rather definitely fixed by economic

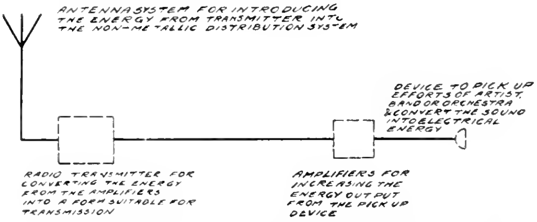


Fig. 2. Diagrammatic Illustration of a Radio Broadcast Distributing System

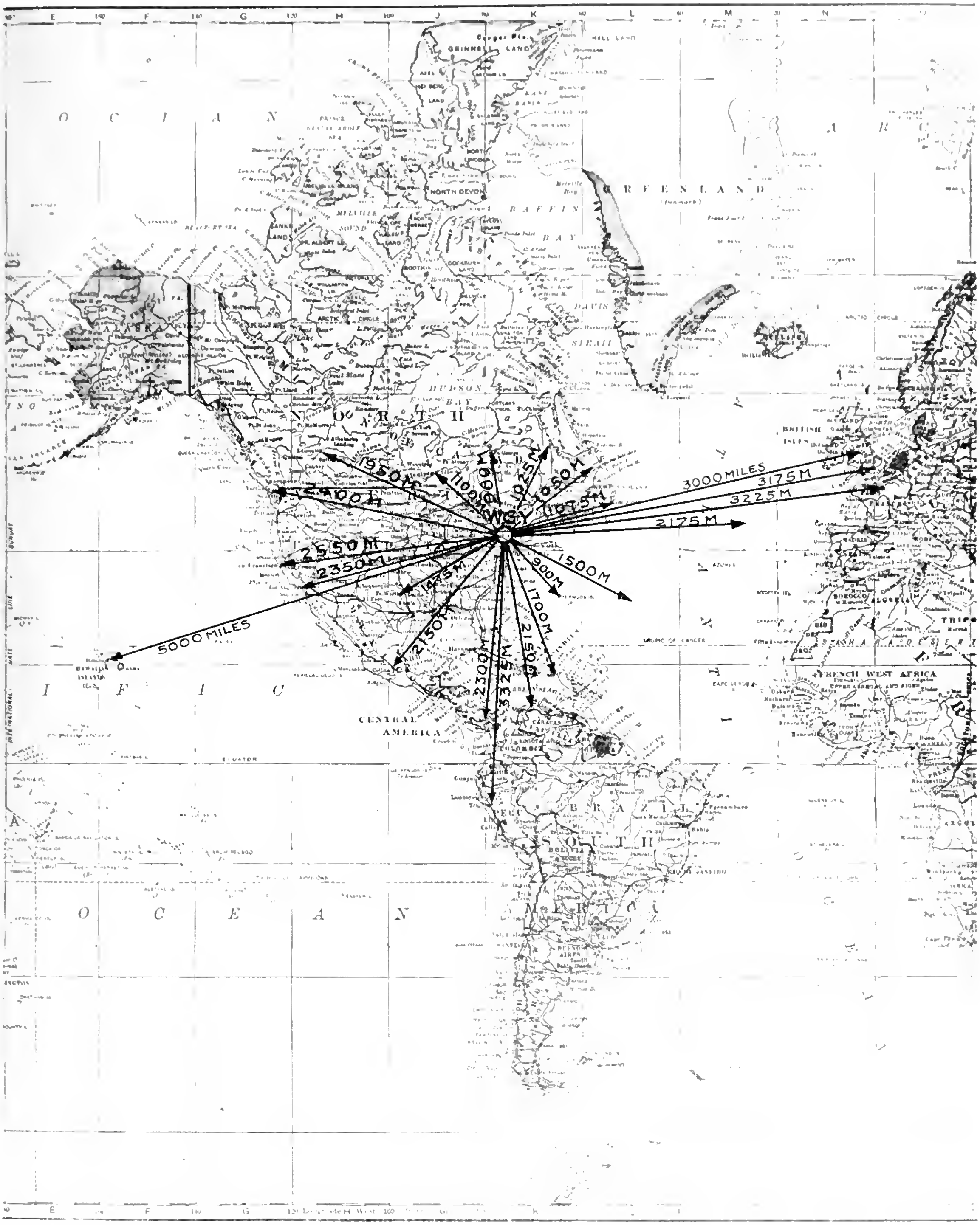


Fig. 3. WGY has received authentic reports of the reception of its programs over the range indicated by the arrows placed on this map of the Western Hemisphere. *(Copyrighted by C. S. Hammond & Co., New York.*

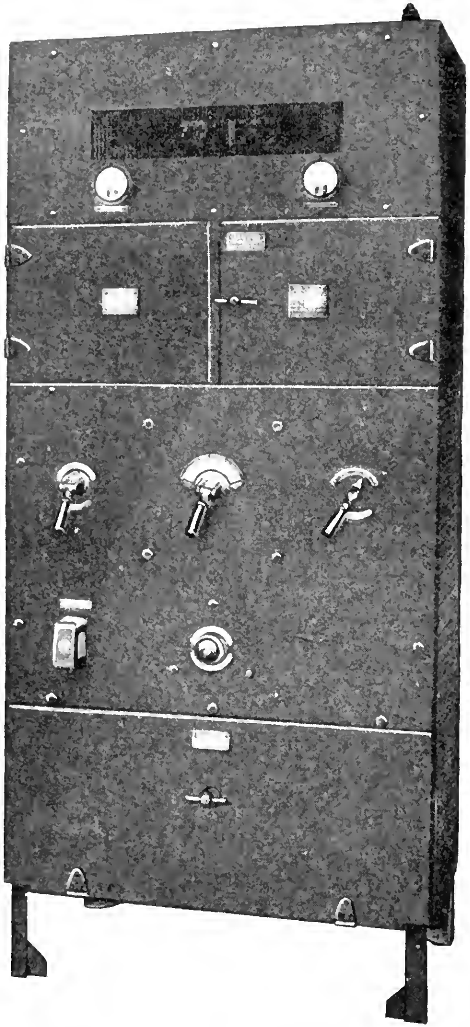


Fig. 4. Commercial Type 1-kw. Radio Transmitter Designed for Continuous-wave and Interrupted-continuous-wave Telegraphy and for Telephony

Fig. 5. Four such 250-watt Radiotron Tubes are Used in the Transmitter shown in Fig. 4 as Oseillators for Telegraphy, and for Telephony Two such Tubes as Oscillators and Two as Modulators

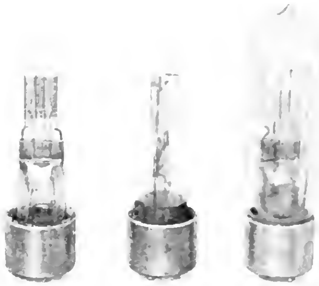


Fig. 6. Three Views of the 50-watt Radiotron Used as a Speech Amplifier in the Transmitter shown in Fig. 4

Fig. 7. Extension Station Equipment for the Transmitter shown in Fig. 4

Fig. 8. Operator's Control for the Transmitter shown in Fig. 4

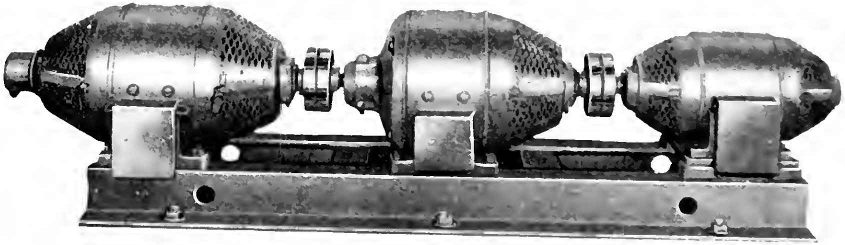


Fig. 9. Three-unit Motor-generator Set for the Transmitter shown in Fig. 4. It consists of a motor, a double-current self-excited generator, and a high-voltage direct-current generator

and operating conditions. On the other hand, the economics of a broadcasting station are rather indefinite and the method of operating is determined by factors far removed from those governing commercial traffic.

It is logical to expect that a broadcasting station would be somewhat similar to the better class of commercial equipments. There is, however, one very important exception in that the broadcasting transmitter has been subjected to numerous refinements which, due to both economic and operating considerations, could not be incorporated in the commercial transmitter. In general, the commercial radio telephone transmitter is required to transmit only that band of voice frequencies necessary to handle commercial telephony. Transmitters for broadcasting purposes must, however, transmit frequencies over a considerably wider band, from the deepest tone of orchestral instruments and organs to the high note of the piccolo flute. The commercial transmitter is required to operate both as a telephone and telegraph set over a considerable range of wavelengths. The control equipment is designed to permit the operating personnel to handle commercial traffic with the minimum amount of switching.

In order to indicate the general similarity between a commercial and a broadcasting telephone transmitter, attention is called to Fig. 4 which shows the type of one-kilowatt radio transmitter built by the General Electric Company for the Radio Corporation of America. This transmitter is designed to provide communication by continuous-wave telegraphy, interrupted-continuous-wave telegraphy, and telephony. In this equipment four 250-watt radiotrons (UV-204), shown in Fig. 5, are used as oscillators when transmitting continuous waves or interrupted-continuous waves. For telephony, two 250-watt radiotrons (UV-204) are utilized as oscillators, two as modulators, and a 50-watt radiotron (UV-203), shown in Fig. 6, is employed as a speech amplifier. The set has a normal wavelength range of 300 to 800 meters. Provision, however, is made so that the wavelength range may be modified to cover the band of 600 to 2000 meters in which case telephony is available up to 1000 meters and continuous and interrupted-wave telegraphy throughout the entire range of wavelengths. On the metal panel forming the front of the unit are mounted the various instruments and controls which are required to handle commercial traffic expeditiously.

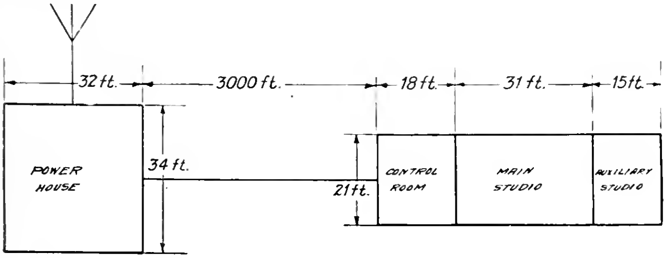


Fig. 10. Diagram of the Physical Layout of Broadcasting Station WGY

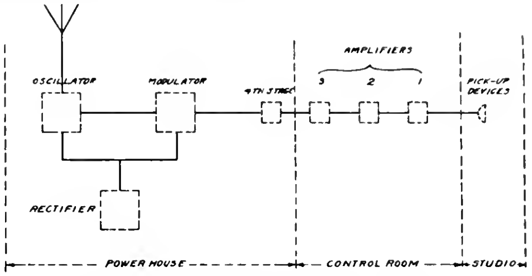


Fig. 11. Diagrammatic Layout of the Radio Equipment of WGY

The extension station equipment and the operator's control are shown in Figs. 7 and 8. The operator's control unit contains switching equipment for starting and stopping the motor-generator. The three-position control switch permits the selection of remote, local, or interphone operation. When in the "Local" position, the operator has complete control of the transmitter. When in the "Remote" position, the send-receive control is transferred to the subscriber's control unit. When in the "Interphone" position, wire telephony is available between the operator and the extension station. The power equipment illustrated in Fig. 9 is a three-unit motor-generator set, consisting of a motor, a double-current self-excited generator, and a high-voltage direct-current generator.

It is evident that a commercial telephone transmitter such as this must contain the fundamental elements of a broadcasting transmitter. The service requirements, however, are entirely different, hence it would be expected that the structure of the equipment would vary considerably in details of design. There is also another essential difference between a commercial equipment and a station such as WGY. A commercial equipment is considered satisfactory if it meets all the traffic requirements imposed upon it. That is, development work on the particular installation stops when the equipment has been manufactured. With the broadcasting station, improvements are always under way and the development work is continuous.

Fig. 12. Building in Which the Main and Auxiliary Studios and Control Room are Located

The general requirements for a broadcasting station such as WGY are as follows:

(1) The station must be ready to operate at all times. This means that the director of broadcasting may at any time handle a special program if he so desires.

(2) Continuity of service is absolutely necessary. In other words, the equipment must be designed and operated in a manner that will prevent an interruption during a program.

(3) The quality of transmission must be of the highest order.

(4) The transmitter frequency must be maintained constant.

These requirements may be summarized by stating that the best possible service must be available at all times.

In considering station WGY it is convenient to divide the equipment into three parts; viz., studio, control equipment, and power plant.

The studio consists of rooms prepared and furnished especially for broadcasting service.

The control room contains all amplifying and switching equipment.

The power plant includes all equipment necessary for the generation, modulation, and radiation of the high-frequency power.

In Fig. 10 is shown the general arrangement of the equipment used at WGY. In order to provide suitable space for the main and auxiliary studios it was necessary to locate this portion of the station some 3000 ft. from the power plant. While it is not absolutely necessary to locate the control room in close proximity to the studio, it was found more convenient to do so in this particular instance.

Attention is called to Fig. 11 as a schematic diagram of the equipment at WGY. Frequent reference to this diagram will be helpful in co-ordinating the various units.

Fig. 13. A Portion of the Main Studio of WGY

THE STUDIO

The studios are located in the building shown in Fig. 12. A general view of the main studio is shown in Fig. 13. All microphone and control circuits are carried in lead covered cables laid behind the wall draperies. Connection boxes are arranged near the floor for the microphone outlets. Fig. 14 shows the announcer's microphone and control box.

The auxiliary studio is of somewhat similar arrangement and differs mainly in that it is considerably smaller. This studio is used chiefly for readings and lectures.

The problem of broadcasting from churches and other places outside the studio has received considerable attention. This is especially necessary when, as in the case of Sunday services, a different church service is broadcast every Sunday. A typical arrangement of pick-up devices is shown in Fig. 16 and illustrates the refinement required in order to transmit every part of the service. These pick-up devices are controlled by a specially designed unit shown in Fig. 15. This control box contains amplifier equipment sufficient to compensate for line losses, etc. Fig. 17 illustrates schematically how the equipment is linked with the control room at WGY. With this equipment an operator located at the church switches the various pick-up devices in and out of circuit according to the requirements of the church service.

Fig. 14. Announcer's Microphone and Control Box on the Phonograph and the Studio Manager's Indicator on the Wall

When it is required to broadcast from a remote point, it is frequently necessary to add additional amplifiers at that location. This requirement of course depends upon the electrical characteristics of the lines between the control room and the remote point. Great care is taken in not only obtaining high quality circuits, but in determining the amount of amplification necessary to maintain the speech always above the interference level.

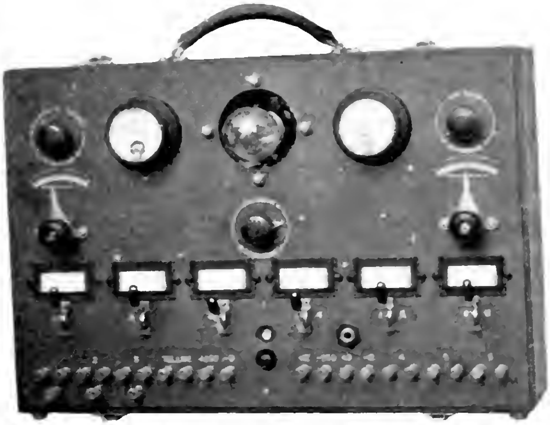


Fig. 15. Portable Control Equipment Used in Broadcasting Church Services, etc.

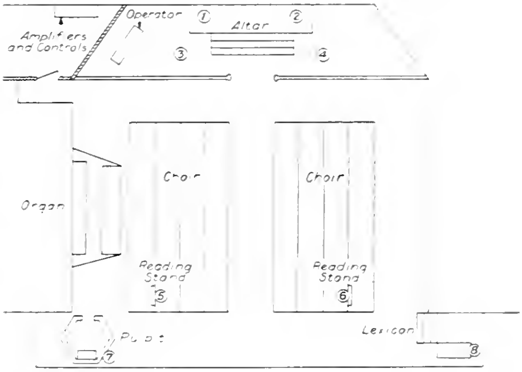


Fig. 16. Typical Layout of the Microphones for Broadcasting a Church Service

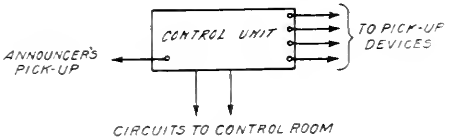


Fig. 17. Diagrammatic Connection of Circuits for Picking up a Church Service, etc.

Pick-up Devices

The pick-up device which is located in the studio is one of the most important units of a station since it is depended upon to transform faithfully the efforts of the artist into a form of energy that can be used by the remainder of the equipment. This unit is receiving an increasing amount of attention. While there are a considerable number of different pick-up devices in use, they may in general be divided into four classes:

(1) Carbon transmitter
(2) Magnetic transmitter
(3) Condenser transmitter
(4) Special types

Two types of microphones in the first class are available and are known as single- and double-button microphones. A microphone of the latter type is shown in Fig. 18. Both types have been used considerably at WGY with very fair results.

The magnetic type of pick-up device as used at WGY not only eliminates some disadvantages of the carbon type but provides a means whereby individual control of certain instruments may be readily accomplished. This is particularly true in the case of the piano. Fig. 21 shows the mounting of two pick-up devices on the piano. In this type of device the vibrations of the sounding board are transmitted to a rotatable coil. This coil, which is placed in a strong magnetic field, has induced in it potentials which are impressed on the grid of a special first-stage amplifier.

With this device, individual control of a vocal selection and the accompaniment is readily accomplished since the vocal selection would be taken care of by a condenser or carbon microphone.

A modification of the magnetic transmitter as used for the piano has been applied to phonograph reproduction, Fig. 19. The transmitter together with a suitable filter has proved quite satisfactory.

One type of condenser microphone is shown in Fig. 20. This pick-up device is probably one of the best types for use in the studio but is somewhat more difficult to apply outside of the station. The general system employed is either to mount the microphone on a cabinet containing at least the first-stage amplifier or to locate the unit near the end of the studio so that the amplifiers may be located in the control room. The condenser microphone requires from one to two additional stages of amplification and operates with a potential of 500 volts between plates.

A new type of pick-up device called the Pallophotophone, Fig. 22, has been used for several types of service. It is dependent for its operation upon the variation of a beam of light. This light is made to fluctuate on and off a light-sensitive cell, the increase or decrease of light causing a corresponding change in the flow of current through the circuit in which the cell is connected. Amplification is obtained in the ordinary way by means of tubes.

Fig. 18. Double-button Carbon Microphone

Fig. 19. Special Pick-up Device on a Phonograph

Fig. 20. Condenser Microphone

The remarkable quality obtained with the device depends upon two main features, which are: (1) the special design of the vibrating system, which is extremely light and responds to vibrations even above the audible range, the amplitude of the mirror movement being many times that of the diaphragm upon which the sound waves impinge; (2) the absence of lag in the operation of the special light cell used, which lag is so pronounced in the ordinary selenium cell.

The pallophotophone as used in the studio is mounted upon a pedestal that can be easily moved from place to place, all the main controls (Fig. 23) being housed in a suitable cabinet and located in the control room.

Fig. 22. Pallophotophone Pick-up Device

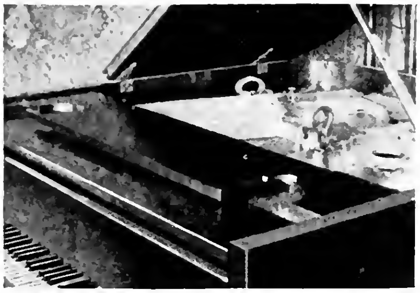


Fig. 21. Two Special Pick-up Devices on a Piano

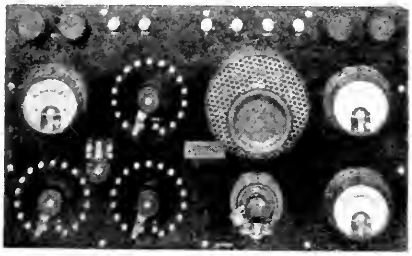


Fig. 23. Control Cabinet for the Pallophotophone Pick-up Device

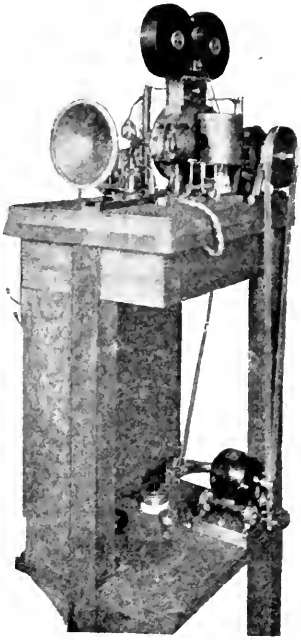


Fig. 24. Pallophotophone Recorder and Reproducer

The arrangement of the device as shown in Fig. 24 may be used to record and reproduce voice or music. In this case a sensitized film is made to pass at a uniform speed behind a narrow opening across which the beam of light is made to vibrate. In this way a sort of oscillographic record is photographed upon the film.

In order to reproduce speech or music, light is made to pass through the narrow slot or opening, through which the record was made onto the light-sensitive cell, and the photographed record is passed back of the opening at the same speed at which the record was taken. The variations of light passing through the opening will correspond to the vibrations produced by the original sound waves, and in this way the reproduction will be the same as if the person talked or sang directly into the device.

In using the reproducer in broadcasting, the electrical impulses are not again converted into sound but are impressed directly on the amplifying system. This method eliminates the distortion that would otherwise be present.

CONTROL ROOM

In order to understand the function of the control room attention is called to Fig. 25 which shows the amplification system. Nos. 1 to 10 indicate first-stage or microphone amplifiers. The microphone circuits from both the main and auxiliary studios terminate in jacks. Four different types of first-stage amplifiers are provided and are selected according to the pick-up device used. The tubes (UV-202) shown in Fig. 26 are used in all cases and are operated at a plate potential from 350 to 400 volts depending upon the type of circuit. The circuits for first-stage amplifiers are shown in Figs. 27 to 30 inclusive. Each first-stage amplifier has its own output control, filament control, and listening-in jack. An assembly of one group of amplifiers is shown in Fig. 34. Certain amplifiers are assigned to various classes of service; e.g., each studio has its own announcing amplifier. In addition some of these amplifiers are used exclusively for broadcasting from places other than the studio.

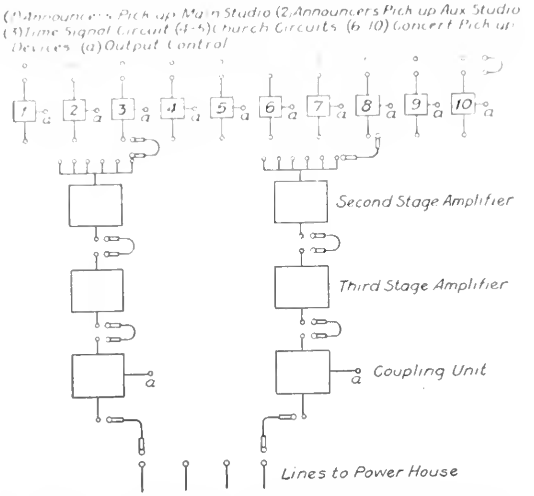


Fig. 25. Diagrammatic Connection of the Amplifying Circuits in the Control Room

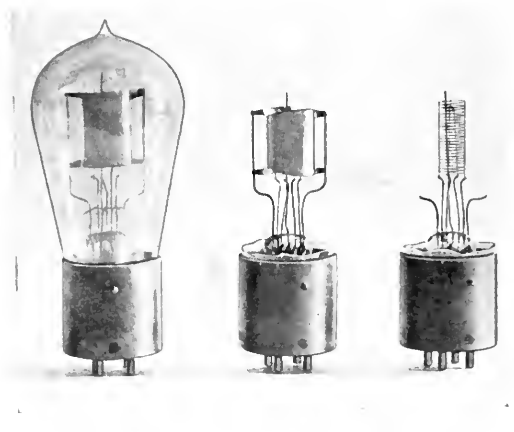


Fig. 26. Five-watt Transmitting Type of Tube Used in the First-stage Amplifiers in the Control Room

The output circuits of the first-stage amplifiers may be plugged into either one of two second-stage amplifiers. The input circuit of the second-stage units includes a number of jacks connected in multiple thus permitting a number of first-stage amplifiers to be plugged into one second-stage unit. The output of the second-stage amplifier may be plugged into either of two third-stage amplifiers. Both second- and third-stage units use one tube (UV-203) operated at a plate potential of 600 volts. The circuit diagram of a second-stage amplifier is shown in Fig. 31 and that of a third-stage amplifier in Fig. 32. Both types of amplifiers use one tube (UV-203) operating at a plate potential of 600 volts. Fig. 35 shows the assembly of a group of second- and third-stage amplifiers with their control equipment.

The output of the third-stage amplifier is plugged into either of two filter units indicated in Fig. 25 as coupling units. The lines to the power house may be plugged into the particular coupling unit in use.

The input and output jacks of all amplifying equipments are located on the control board as shown in Fig. 33. The lamps at the top of this switchboard are a part of the signalling system.

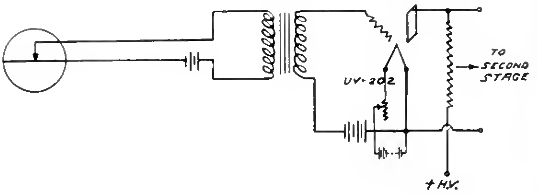


Fig. 27. Single-button Microphone and First-stage Amplifier Connections

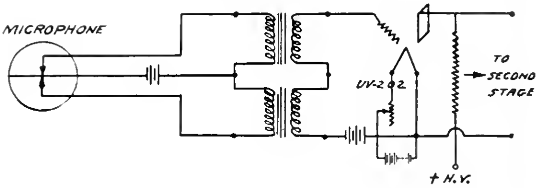


Fig. 28. Double-button Microphone and First-stage Amplifier Connections

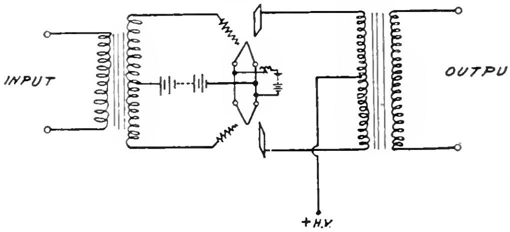


Fig. 29 Push-pull Amplifier Connections

Power for the filaments of all amplifiers is obtained from storage batteries. The plate supply may be obtained either from a direct-current generator or storage batteries. All power supplies are in duplicate, usually by providing both a battery and a generator. The battery equipment is illustrated in Fig. 36.

Time-signal Receiver

The receiving equipment necessary to reradiate the government time signals is located in the control room. This apparatus is shown in Fig. 37 and consists of a trap circuit, tuning unit, and amplifiers.

The equipment might be considered as a special pick-up device for time-signal service. The government time signals are received and amplified until the output is equivalent to that of the ordinary studio pick-up device. The output of the time-signal equipment is connected to a first-stage amplifier used solely for this service.

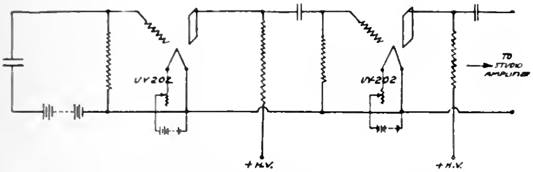


Fig. 30. Condenser Microphone and Connections of Associated Amplifiers

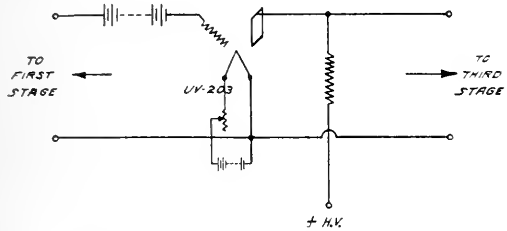


Fig. 31. Second-stage Amplifier at WGY

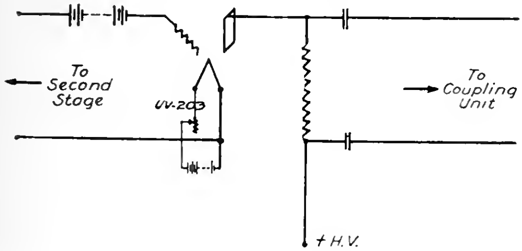


Fig. 32. Third-stage Amplifier at WGY

POWER HOUSE

The power house is located in the building shown in Fig. 38. The apparatus employed is comprised in general of the following equipment, which is provided in duplicate:

(1) High-voltage direct-current supply consisting of one or more batteries of kenotron rectifiers.

(2) High-frequency generator utilizing one or more radiotrons as oscillators.

(3) Modulator unit consisting of one or more radiotrons as modulators.

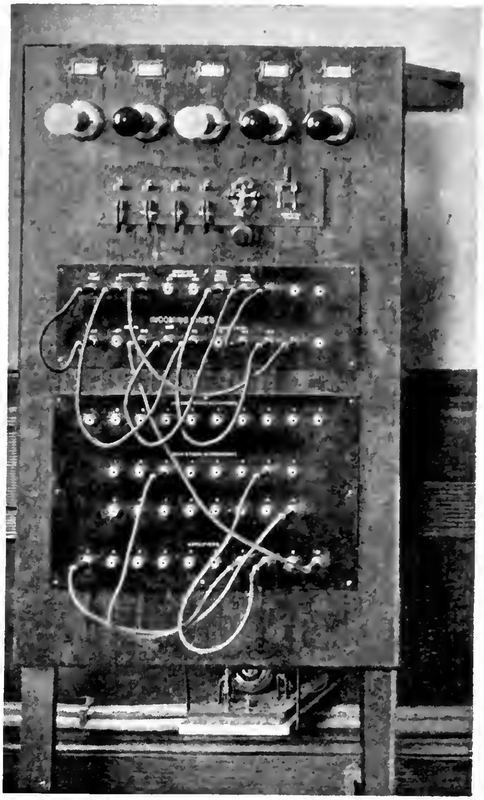


Fig. 33. Control Board for Amplifiers at WGY

Antenna

Fig. 38 also gives some idea of the antenna employed at WGY. It is of the multiple-tuned type having two tuning points. An extensive counterpoise system is utilized, a portion of which can be seen in Fig. 39, which also shows the outdoor tuning coil. The second multiple-tuning coil is located in the power house and serves to transfer power to the antenna. The towers are placed 352 ft. apart and are 165 ft. high above the building top which is itself 96 ft. above the ground. The length of the flat top portion of the antenna system is approximately 200 ft.

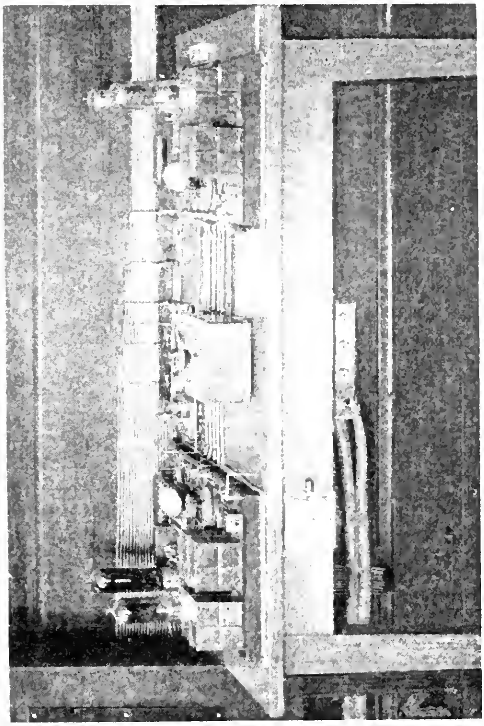


Fig. 34. ~~First stage~~ 2nd & 3rd Stage Amplifier at WGY

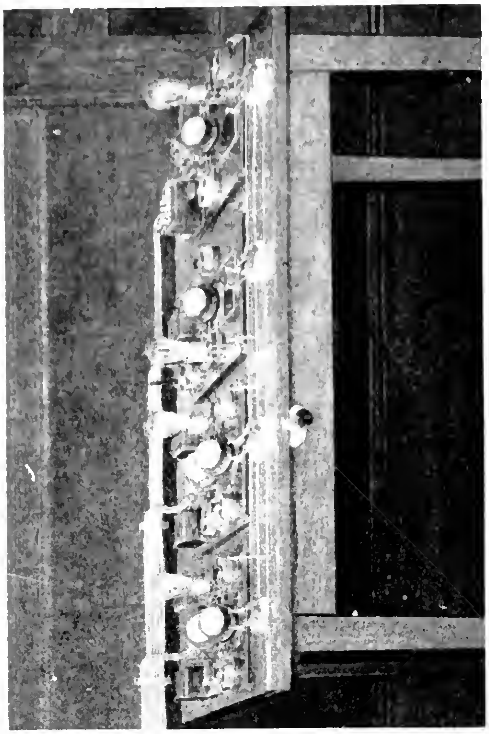


Fig. 35. ~~Second and Third-stage~~ 1st Stage Amplifiers at WGY

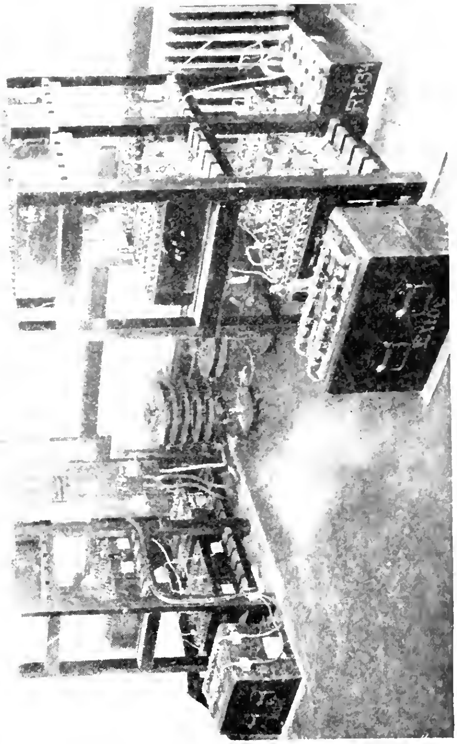


Fig. 36. Battery Racks in Control Room

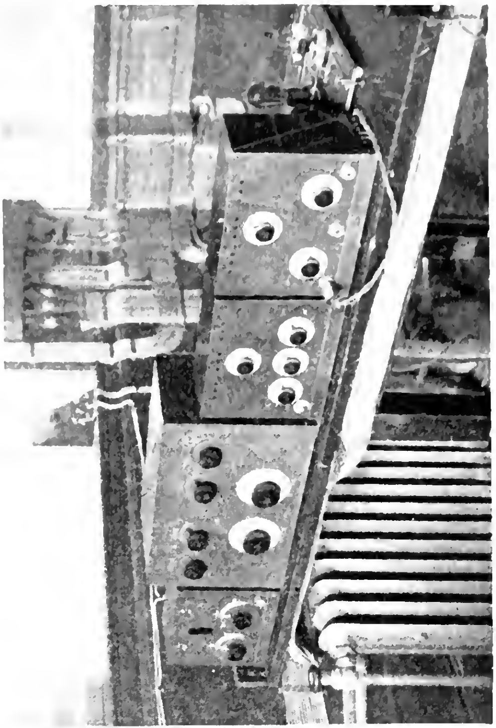


Fig. 37. Receiving Equipment for Re-radiating Government Time Signals

Rectifier Equipment

The direct-current supply for the plate circuits of the tube equipment used for the generation and modulation of the high-frequency power is obtained from a battery of kenotron rectifiers. The present equipment with its filter is capable of delivering power at 12,000 volts with a ripple of less than one-tenth of one per cent. The schematic circuit diagram is shown in Fig. 40 and the actual construction is indicated in Fig. 42.

Fig. 38. Broadcasting Towers and Antenna of WGY. The power house of the station is in this building which is located at the center of the Schenectady (N. Y.) Works of the General Electric Company

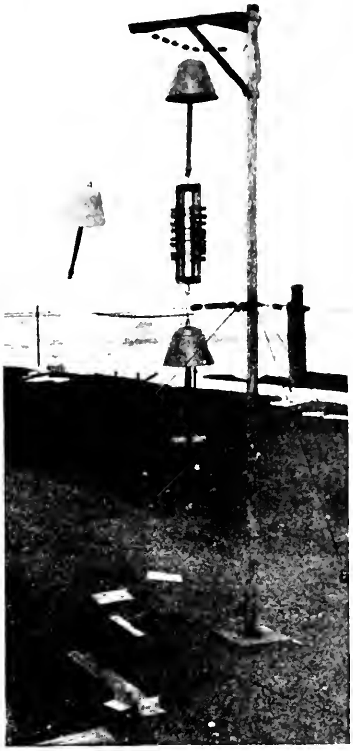


Fig. 39. A Portion of the Counterpoise and the Outdoor Tuning Coil at WGY

In this rectifier the delta-connected primary is supplied from a 3-phase 220-volt generator. The high-tension windings of the transformer are connected to form two Y's 180 deg. out of phase. Each Y with its kenotrons is thus a half-wave rectifier delivering voltage waves E_1 and E_2 with the odd multiples of the triple-harmonic component in the two Y's 180 deg. out of phase, and the even components in phase. If the neutral points of the two Y's are connected through a reactance and the load connected as shown, the odd multiples of the triple-harmonic component will not appear in the rectified voltage wave whereas the even harmonic components will appear. The voltage across the reactor or interphase transformer is the sum of the absolute values of the triple-harmonic frequency voltage due to each Y. The current due to this voltage is interphase transformer magnetizing current, and circulates through the kenotron and transformer windings without appearing in the load.

The current waves drawn through each kenotron are nearly square lasting for one-third of the cycle. Since there are two high-tension windings per phase passing current in opposite directions, the primary current wave is symmetrical and contains no even harmonics. The direct-current component of current delivered by each of the two Y's is one-half of the total direct current so that each tube is required to pass only one-half the maximum value of current required per tube in the ordinary three-phase full-wave rectifier. The tube equipment consists of six kenotrons (UV-218) one of which is shown in Fig. 43.

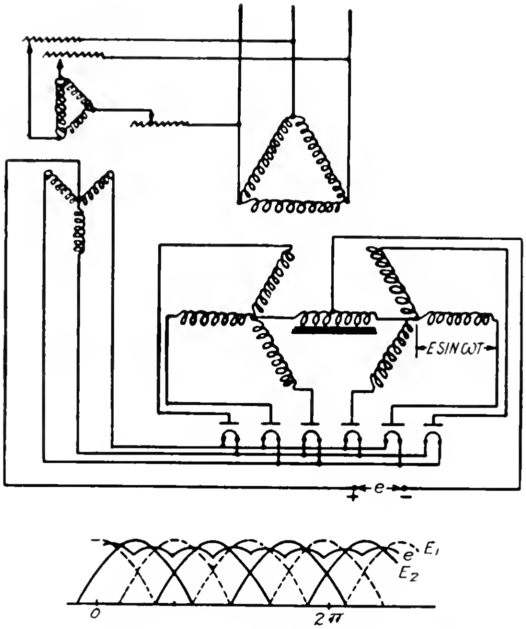


Fig. 40. Diagrammatic Connection of Circuits of the Battery of Kenotron Rectifiers at WGY

Oscillator and Modulator Units

The oscillator circuit is shown schematically in Fig. 41. It utilizes a tank circuit loosely coupled to the antenna so that the frequency is determined chiefly by the constants of the tank or dummy circuit. The oscillator utilizes one tube (UV-208) operating at reduced output. This tube is shown in Fig. 45; and the complete oscillator and modulator assembly is shown in Fig. 46.

The modulator employs five tubes (UV-206) such as shown in Fig. 44. The modulating system is that commonly known as the plate method of modulation. This modulation unit also includes an amplifier known as the fourth stage of amplification. The amplifier consists of two units, a push-pull and a reactance coupled amplifier. Either unit may be used depending upon operating conditions. Both units use tubes (UV-204) operating at a plate potential of 2000 volts.

In addition to the apparatus mentioned, the power house contains the necessary generators and batteries together with an oscillograph, power controls and auxiliary switches.

OPERATION

In order to understand the duties of the operating personnel and the functioning of the signalling system, it is desirable to trace the operation of the station during the transmission of a program.

The station is manned one-half hour before the program is to start and all clocks are checked from the master clock. The two power men on duty measure the insulation of the tie lines to the control room, check all batteries, and operate the entire equipment into an artificial antenna. The senior power man then throws a switch which operates signal lights in the control room and studio indicating that the power house is ready but that power is not on the antenna. So far as the power house is concerned, the set is in operation and the two operators begin to perform their regular duties. The senior power man supervises the operation of the power equipment, monitors the radio output, and watches the modulation indicators in various parts of the circuit. By means of signal lights he informs the control room whether the modulation should be increased or decreased. In case of emergency he communicates with the control room over the intercommunicating system. The junior power man takes all readings and records them in the log at the beginning of each selection. In case the selection is a long one the readings are recorded every ten minutes. This finishes the picture insofar as the power house is concerned. These men must keep the station running until directed by the control operator to shut down.

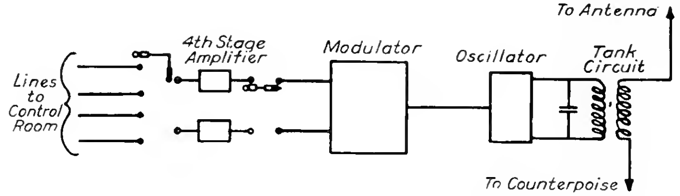


Fig. 41. Schematic Diagram of Power House Circuits

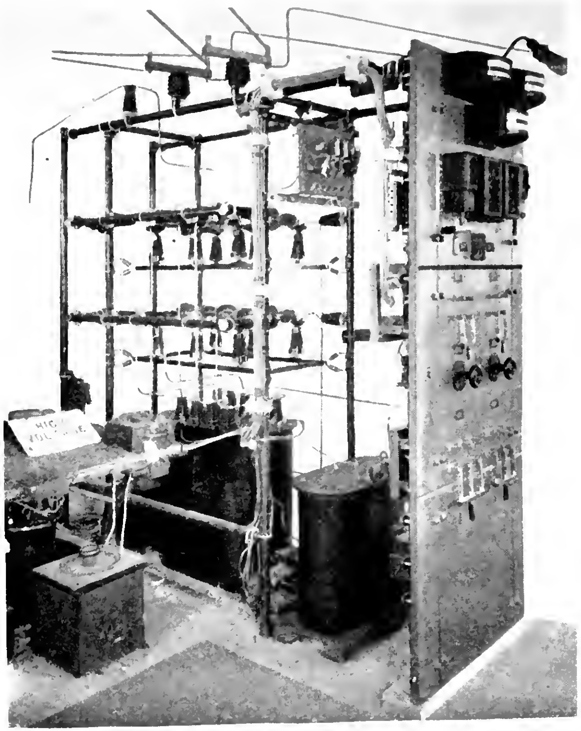


Fig. 42. Kenotron Rectifier Assembly

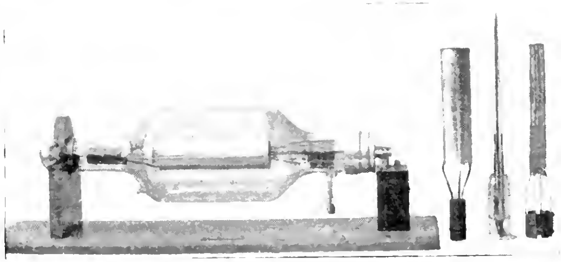


Fig. 45. Radiotron Used as an Oscillator in the Circuit shown in Fig. 41

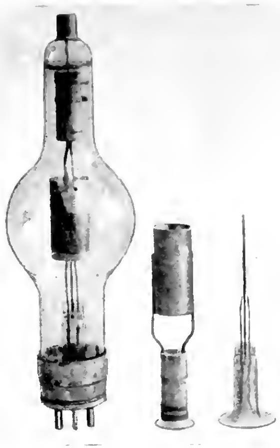


Fig. 43. One of the Kenotron Rectifiers Used in the Equipment shown in Fig. 42

Fig. 44. Pliotron Used as Modulator in the Circuit shown in Fig. 41

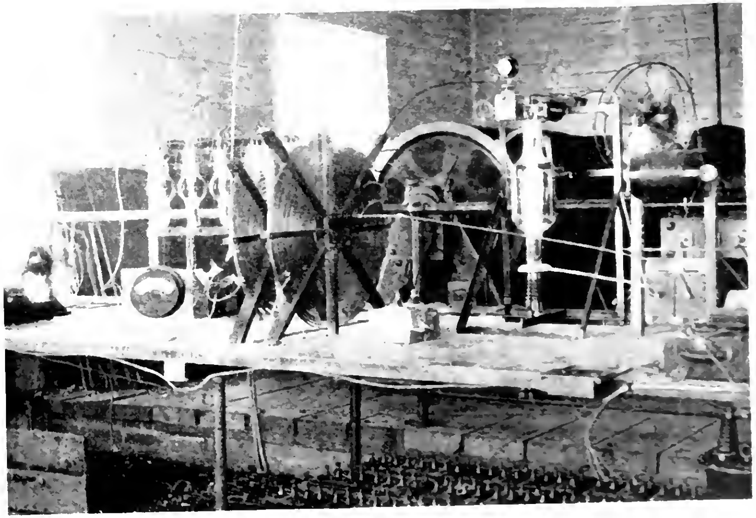


Fig. 46. Complete Oscillator and Modulator Assembly Illustrated Diagrammatically in Fig. 41

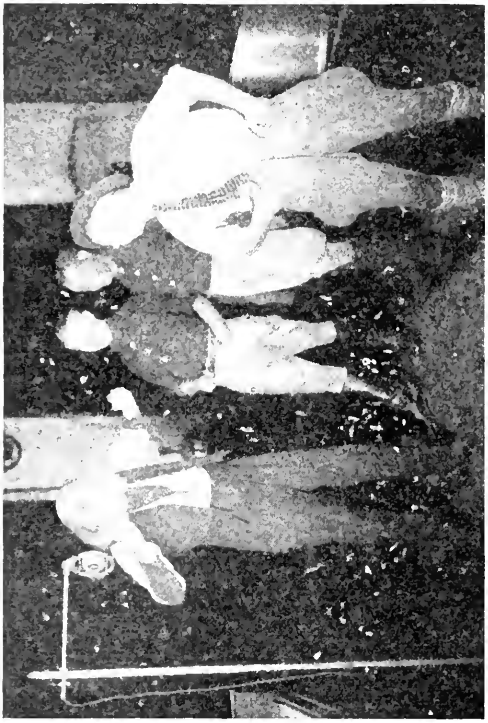


Fig. 47. Actors Broadcasting a Drama from WGY

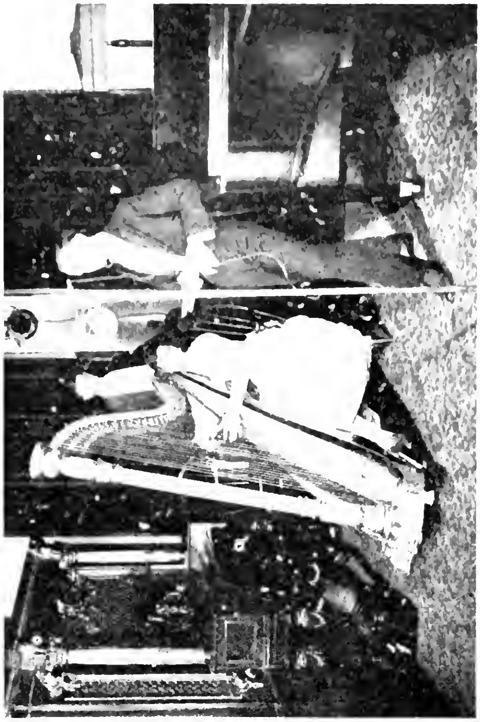


Fig. 48. Announcing the Rendering of a Harp Selection

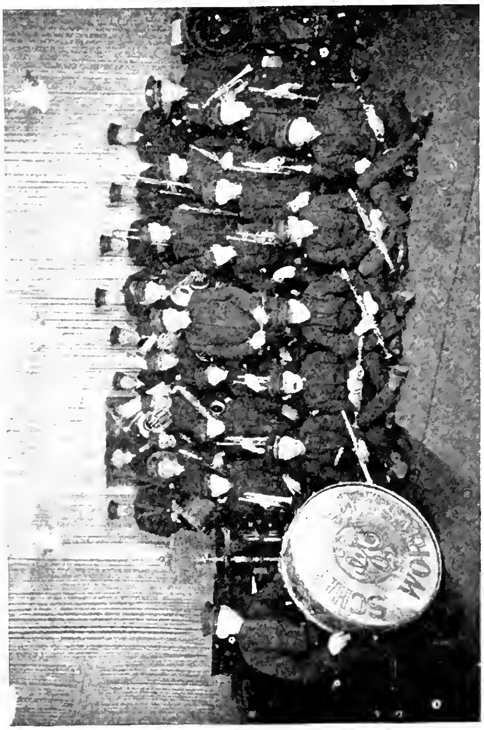


Fig. 49. Band Grouped in the Main Studio

Fig. 50. Orchestral Music Being Broadcast from WGY

Coming back to the control room we find that the operators have checked all batteries, amplifiers, and pick-up devices and have connected in those required for the program.

In the studio, we find the announcer and his assistant arranging a group of artists. All artists not performing remain in the reception room where a loud-speaking reproducer permits them to hear the other numbers of the concert.

Assume that the artists are placed and the control room has received a signal to this effect. The senior control man throws a key which, operating contactors in the power house, transfers the set from the artificial to the regular antenna. The radiation from the antenna operates a green signal light in the control room and studio. The announcer throws a small key to its "Announce" position which through contactors connects the announce microphone and its set of amplifiers and also lights red warning signals in the studio and control room. While the announcement is being made the control man has grouped the amplifiers and pick-up devices for the first selection. After the announcement has been made, the announcer throws his key to the "Concert" position, automatically disconnecting the announce microphone and connecting in the proper concert amplifiers and pick-up devices.

In the control room the senior operator controls the grouping of the amplifiers and monitors the radio output. The assistant operator takes all readings for each selection, records them in the log, and also checks the output of the amplifiers. A third operator keeps a 600-meter log and answers telephone calls. This operator also has control of a one-kilowatt commercial transmitter adjusted for telegraph operation on 300 or 600 meters. This transmitting equipment is quite similar to the commercial transmitter previously described.

In case the pick-up device has been located incorrectly and the control men cannot compensate by any adjustment of the amplifying equipment, a small electric sign is lighted in the studio. This sign is located where it is not visible to the artist and indicates whether the location is wrong with respect to the soloist or the accompanist. It also indicates the general nature of the trouble. If possible the studio manager then makes the necessary correction in location.

Studio Operation

A great portion of the success of any broadcasting station depends upon the operation of the studio. The proper placing of the artist and the relation of the various instruments of the orchestra, band or chorus, affects the transmission very materially. Even for the radio play where a number of pick-up devices may be used or where different pick-up devices are used for the various instruments, the broadcasting may be ruined by improper placement of the performers. In cases where a separate pick-up device is used for some instrument such as the piano and where the soloist has an individual pick-up, the location is somewhat simplified since the relative intensities may be regulated by the individual controls associated with each pick-up device.

The acoustic properties of the studio also have a decided effect on the placement of the pick-up device, especially for music. Obviously the best method of determining the proper location of the microphone is by actually testing with the artist. This not only assures satisfactory operation during the performance but permits a gradual education of the studio manager in locating the artist and microphone to obtain the best results.

Probably the ideal condition would obtain if the pick-up device could be definitely located and the control equipment used to obtain the desired effect. This could be accomplished if, for example, each instrument in an orchestra had a separate pick-up device. In general, the individual pick-up idea has worked out very satisfactorily for a limited class of broadcasting. In this class is the radio show, the musical comedy, and similar performances. The radio show in particular requires the use of individual pick-up devices; for instance, some casts contain from 12 to 15 performers. The use of individual microphones together with a knowledge of the play and the general characteristics of each performer permits a selection and grouping of pick-up devices which gives the most realistic results. This, however, does not stop with the performers but includes the various stage effects such as wind, the ringing of a door or telephone bell, the slamming of a door, the scratching of a match, etc. These effects are very important in order to assist the imagination of the radio theater-goer.

Obviously the operation of the studio is one of the most important and is probably destined to be the most important part of a broadcasting station. While the entire broadcasting equipment may be the best possible, unless the output of the studio is absolutely correct the desired effect on the listener is not obtained.

Typical studio settings are shown in Figs. 47 to 50 inclusive, and on the cover of this issue of the Review.

QUALITY

It has been indicated that a broadcasting station is good to just the extent that the output of the pick-up device represents the efforts of the artist. This assumes that the balance of the equipment when actuated by the output of the pick-up device does not introduce distortion. The distorting effects may be due to either the acceptance or suppression of a particular frequency or band of frequencies. For example, a unit might amplify some frequencies considerably better than others thus resulting in accentuating those particular frequencies. Distortion may also result from overloading some unit with the result that while faithful reproduction occurs, so long as an impulse does not exceed a certain amplitude, all impulses having amplitudes in excess of this limiting value are decreased proportionately.

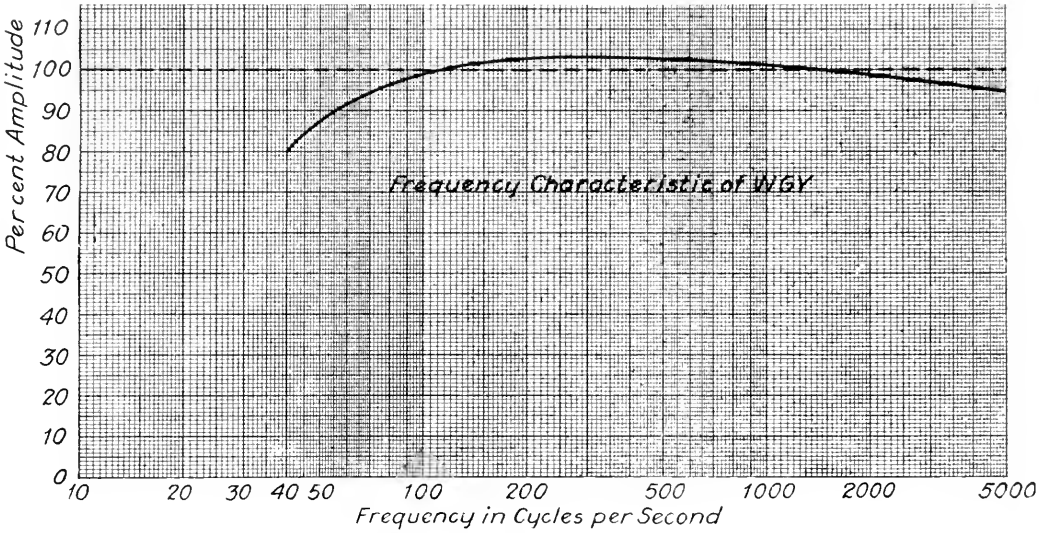


Fig. 51. Curve Showing the Practically Flat Audio-frequency Characteristic of WGY

While these are but a few of the ways wherein distortion may be introduced, they indicate the care which is required to obtain the high quality of transmission necessary for a broadcasting equipment. The overall frequency characteristic of WGY is shown in Fig. 51. The dotted line represents the condition that should exist for theoretically perfect transmission. The solid line indicates the actual frequency characteristic obtained. This characteristic was obtained by substituting a source of power for the pick-up device, hence any distortion due to the pick-up is not considered. It should be noted that the essential frequency band (100 to 5000 cycles) approximates very closely the ideal characteristic.

RANGE

Probably the most indefinite factor of a broadcasting station is the range. Not only is the range affected by the usual conditions incident to radio transmission, but in broadcasting it is further complicated by the lack of a common basis of agreement for defining the term. In commercial work the range generally indicates the distance over which commercial traffic can be handled satisfactorily. With broadcasting the reception of even a small portion of a concert, or just sufficient information whereby the station may be identified, immediately establishes a new record.

It is nevertheless interesting to observe the distances that have been obtained. The map shown in Fig. 3 indicates some of the distant points from which reports of WGY have been received. In each case the report of the reception gave sufficient information to prove definitely that the writer had received an appreciable part of at least one program.

Observations on Electric Railway Practice

By W. B. Potter

Chief Engineer, Railway Department, General Electric Company

Mr. Potter recently spent several months in Europe studying railway practice. This paper is based on his observations. He treats his subject very broadly and his comments should be both of interest and use to engineers in this country and abroad. This paper was presented to a double meeting of the American Institute of Electrical Engineers with part of the members and the speaker assembled at New York City and another group of members gathered at Chicago. Wire connections between the two cities terminating in "loud speakers" made the remarks at either meeting place audible at both. There was also a wire connection to the WEAF broadcasting station in New York, bringing the speech to an unknown number of widely scattered radio listeners. Duplicate sets of lantern slides were shown synchronously at both cities.—Editor.

The development of rail transportation since the day of stage coaches and horse drawn tram cars, has been a process of evolution in which some reminders of the past are still noticeable.

Before the days of steam, the track gauge used for the tram cars of the British coal mines was presumably the origin of the odd dimension of 4 ft. 8½ in., which has become so generally accepted as the standard track gauge of the railroads of today. In Great Britain freight cars are still called "waggons," and many of the older passenger vehicles there and on the continent are a sort of multiple unit stage coach in arrangement and interior fittings. These passenger coaches are much as if several coach bodies were mounted on a flat car, and to carry out the illusion, the exteriors of the separate compartments are sometimes so paneled as to resemble the outlines of a coach. The doors, windows and the interior are as nearly like the old stage as one could imagine, not omitting the looped strap arm rest for those sitting at the ends of the seats.

The modern European passenger cars, although retaining the compartment plan, are usually provided with a corridor throughout and vestibuled passage between the cars. These cars are well equipped, comfortable and afford a privacy which we do not enjoy without extra price.

Our first electric cars were converted horse-cars, and in keeping with their previous motive power, there was at first a disposition to use much smaller motors than were suitable. About one and one-half horse power was probably a fair average for the old horse-car; and where two horses had served, an equipment of two 10-horse power motors seemed out of proportion despite the improvement in schedule.

While the speed was limited in the horse-car days there was progress in other respects, of which one instance is worthy of note. Perhaps some of you may remember the red glass panel in the monitor of the Stephenson horse-cars that once ran in New York. This panel was inscribed with the legend, "This car is equipped with super-springs, contributing to quiet and ease." You may also remember riding in these cars and the comfort derived from reading this sign—it at least had the merit of auto suggestion!

The single truck of the old horse-car was not suitable for the higher speeds and longer car bodies soon called for in electric service. The bogie or double truck motor car so generally used today was a natural adaptation from steam railway practice, and the simplicity of this design was early appreciated as advantageous for electric locomotives. One of the first electric locomotives used in regular service in this country was an electrically equipped bogie truck railway express car. The motor car practice of mounting geared motors directly on the axle has been quite generally applied and proven very satisfactory for electric locomotives. In continental Europe the development of the electric locomotive seems largely to have been carried out with the idea of substituting the electric motor for the steam locomotive cylinder and retaining the feature of connecting rod drive.

While there is a similarity in the character of traffic and the conditions under which it is carried on in the European countries, there is a great difference in these respects between Europe and this country. The influence of precedent, experience and individual opinion under these quite different conditions, has naturally led to a different viewpoint and to some differences in practice between this country and Europe. There is much to commend and little to criticize in the railway practice and equipment, as it exists in the different countries. Each country has endeavored to provide transportation of a character most suitable for its particular requirements. Occasional visits to any country do not give opportunity of becoming well informed on this subject comprehensively, but even casual observations, as in this instance, may serve as an excuse for comment and comparison.

The weight of European freight trains and the maximum draw-bar pull allowed are about one-quarter of what they are in this country. The weight of their passenger trains is about one-half. The permissible weight on driving wheels is about two-thirds and the weight per axle of their cars is about one-half of our usual practice. The low draw-bar pull and car weight permit a relatively light mechanical design of rolling stock, and the requirements as to strength are further made easier by the method of car coupling.

The screw coupler, i.e., two clevises connected by a rod with a right and left hand thread, is used almost universally. Each draw-bar has a hook that is provided with a screw coupler, and in the process of coupling the clevis of one of the couplers is thrown over the hook of the other draw-bar, and the cars in effect are jack-screwed together by hand. There are two mushroom shaped buffers with faces about one foot in diameter; the right one having a rounded face and the left one a flat face, these are located near the outer end corners of the car. The initial tension on these buffers is about 2000 lb., and when fully compressed the pressure is approximately 20,000 lb. As might be

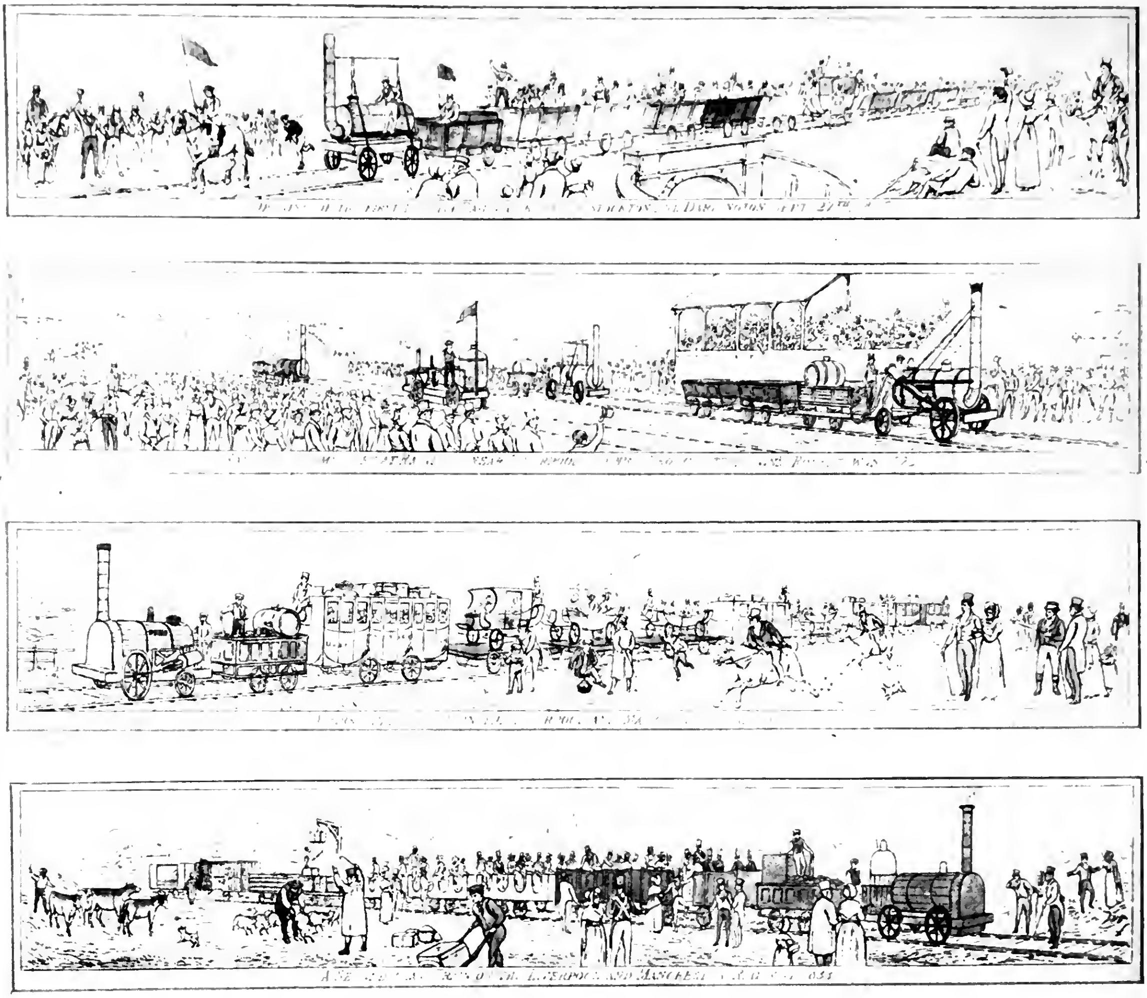


Fig. 1. Reproductions from Old Prints Illustrating the Early Days of Steam Railroads in England

expected, there is ordinarily no shock when coupling with this kind of a coupler as a slight compression of the buffers is all that is required. With our automatic couplers the shock of coupling is occasionally in the nature of a crash.

Admitting the advantages of the automatic type of coupler, the use of the screw coupler does permit a much lighter end framing on locomotives and cars. An inquiry as to European experience with automatic couplers brought forth the comment that the couplers were all right, but that the process of coupling wrecked the rolling stock. Allowing for various requirements, the weight of European electric locomotives is from two-thirds to three-quarters the weight of electric locomotives in this country having the same horse power.

The speed of European trains on the average is rather higher than in this country. Many of the European cars have two or three axles, which does not seem to be a wheel arrangement that would provide for smooth running. In many instances these cars have no truck framing, but depend upon the car springs to hold the axles in alignment. These springs are usually about six feet long and semi-eliptical in shape, although so little curved as to be nearly flat. The springs bear directly on the journal boxes and are so resilient that the vertical shock from track joints is very well cushioned. The shorter wheel base two-axle car and many of the three-axle cars have a tendency towards transverse oscillation, which may be decidedly uncomfortable unless the cars are properly coupled together. The combination of the screw coupler and buffers has more influence in steadying the car and preventing oscillations than might be supposed. When the coupling is set up sufficiently to compress the buffers, the friction between them is sufficient to prevent any relative movement, so that each car is steadied by the one to which it is coupled.

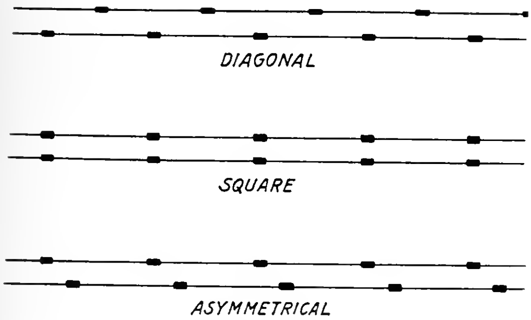


Fig. 2. Different Plans of Locating Track Joints to Illustrate Effect on Transverse Oscillations of a Car

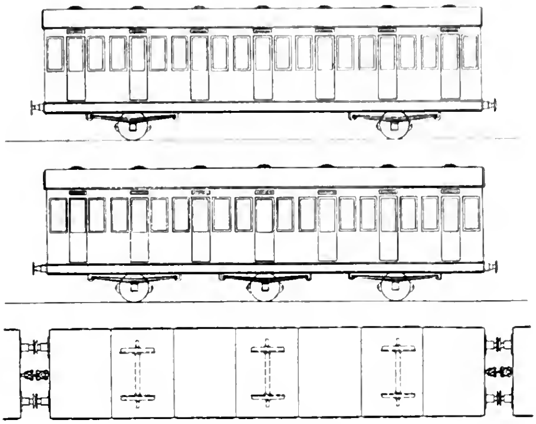


Fig. 3. Outline Drawings of the Large Two- and Three-axle Cars Used on European Railways; weight 20 to 23 tons; seating 35 to 72 passengers, depending upon the class; overall wheelbase 28 to 30 ft. The plan shows the arrangement of screw coupler and car buffers

On a fast train made up of similar cars having bogie trucks, there was a noticeable difference in the riding qualities of those cars on which the couplers had been screwed up and certain others so loosely coupled that the buffers did not touch. It is the usual practice to screw up the coupler sufficiently to compress the buffers, but there are exceptions. A remembered instance was a trip on a two axle car of about 14 ft. wheel base which was loosely coupled to the rear end of a passenger train. At a speed of about 55 miles the transverse oscillation, or "side slogger" as it has been called, was so bad as to cause some apprehension to the uninitiated. At the first stop the coupling was screwed up, which was all that was necessary to effectually check the "slogging." The frequency of these transverse oscillations appeared to be the natural period of the car body as established by the scheme and proportions of its flexible supporting structure. The track did not seem to induce any supplemental oscillation.

The method of locating track joints perhaps has more influence on the running quality of the rolling stock than is commonly appreciated. The European practice is to lay the track with square joints, i.e., with the joint of each rail directly opposite. The customary practice in this country is to lay the track with joints spaced diagonally and located midway between the opposite rail. The trial run of an electric locomotive over a track with square joints, which were in poor condition, afforded an exceptional opportunity to observe the reaction of a track with this arrangement of joints. This locomotive had bogie trucks and at about 60 miles an hour there was a very decided vertical vibration, but no tendency whatever toward enforced side oscillation. With diagonally laid joints, in as poor condition, it is questionable whether any locomotive or car could have been run at that speed without something giving way; particularly if the transverse oscillation, which is diagonal in direction relative to the track, had happened to synchronize with a diagonal location of the low joints. Only one railway in Europe was noted where the rails were laid with diagonal joints. The manager remarked that his electric motor cars were subject to so much oscillation that it was his intention to relay this track with square joints.

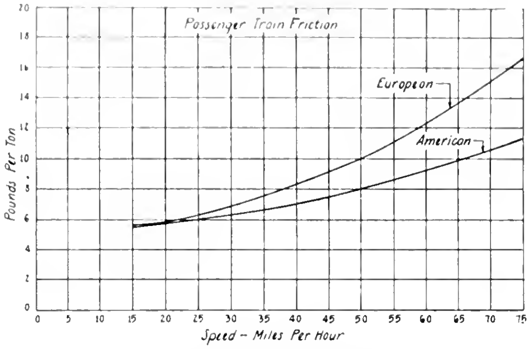


Fig. 4. **Curves Showing the Relative Train Friction of European and American Passenger Trains. The difference is principally due to the lighter weight of the European cars**

A comparison of the influence of square and diagonal joints on the running qualities of a motor car was recently observed in this country, over a line having both kinds of joints. On the portion of track having square joints, there was observed a slight steady oscillation of uniform character at the rate of about 150 per minute; on the portion of track with diagonal joints the same car did not oscillate with equal steadiness and at times had a noticeable swing toward one side or the other. As the car was running at about 60 miles per hour, the natural period of oscillation did not correspond with the location of the diagonal joints. Had the vibration synchronized with the joints, an enforced and increased oscillation might reasonably have been expected. This particular track was in good condition throughout.

There is no doubt that track laid with square joints is more difficult to keep up as the impact on the ballast is more severe when both wheels strike the joints simultaneously. With the less weight per axle customary in European practice, it is much easier to maintain their track, than it would be with our heavier weights per axle.

The writer suggests that it might be possible to secure the advantage of diagonal joints in respect to track maintenance and the steadier running quality of square joints, by laying the track with joints asymmetrically spaced, that is, instead of overlapping a half rail length, to overlap between one-quarter and one-third, preferably a length of lap that would not be an even fraction of the rail length.

There was observed on the Great Northern Railway, England, an articulated arrangement of cars into groups, which is a departure from the conventional car with two bogie trucks. This articulation is accomplished by locating a truck midway between each of the several cars in the unit group, so that the number of trucks is only one in excess of the number of cars constituting the group. In the suburban service the trains were composed of two groups each of four cars, thus requiring ten trucks for the eight cars. On the main line the train was made up of a number of individual cars and a five-car articulated group. The reduction in weight as compared with two bogie trucks for each car, was said to be about 10 per cent; it was also stated that the train friction was reduced. A noticeable feature on the main line train at high speed was the smooth running of the group; the riding was exceptionally good and noticeably better than individual cars in the same train.

In the brief reference to electric locomotives, the motor car and steam locomotive were mentioned as prototypes, which have influenced the trend of electric locomotive development. To elaborate, there are at least seven general designs of driving mechanism or methods of motor mounting under which electric locomotives may be classified. These different classes may be briefly described as—axle geared, quill geared, outside geared, axle gearless, quill gearless, direct connected side rod and geared side rod.

Each of these designs, with the exception of the outside gear, is employed in this country. In England, the axle geared drive has been most generally used, but there has been completed recently a high speed locomotive for the North Eastern Railway equipped with the quill geared drive. The side rod drive does not seem to have met with favor; the following reference to side rod drive is quoted from a paper by Sir Vincent Raven before the North East Coast Institution of Engineers and Shipbuilders, December 16, 1921.

> On the Continent, notably in France, Switzerland, Italy, Germany, Austria and Sweden, the connecting rod drive in one form or other is almost universal. Up to the present electrification in these countries has been carried out mainly on the single-phase or three-phase system and Continental Engineers consider that the additional complications caused by the introduction of cranks and coupling rods are more than compensated for by the advantage of having a free hand with the motor design.
>
> A large number of designs have been worked out. Some have proved quite satisfactory, others have given rise to a good deal of trouble. In most cases the trouble has been eliminated by strengthening up special parts such as crank pins, Scotch yokes, etc., and by introducing a certain amount of flexibility into the connections between the motors and the crank shafts.

The mechanism of the motor-driven side rod drive needs to be maintained in close adjustment and may reasonably be expected to require more attention and have a higher cost of maintenance than some of the other methods of transmitting power to the drivers.

The transmission of power from a motor-driven crank, whether direct connected or geared, introduces strains in the connecting mechanism somewhat different from those which occur in a steam locomotive. With the best adjustment and with operating clearance only in the bearings, the motor-driven connecting rods on either side transmit alternately the power through 90 degrees, except for such spring of the parts as may cause the rods to work together for a brief interval. As this transfer of the power from one rod to the other takes place at about 45 degrees from the dead center, the pins, connecting rods and included frame will be subjected to the full strain of driving when the crank is at an angle of about 45 degrees. If the two sides are not in even adjustment this angle may be even less.

Aside from centrifugal forces and the shock due to lost motion in the driving mechanism, the stress in the rods, pins and frame of a steam locomotive is limited and may be predetermined from the size of the cylinder and steam pressure. With a motor-driven crank the stress is dependent on the crank angle and is affected by the adjustment of the mechanism.

As an extreme illustration, one side of a steam locomotive may be stripped and with the other side on dead center, the throttle may be opened wide without damage to the locomotive. Under the same conditions with a motor-driven crank, the resultant toggle action would set up enormous stress and undoubtedly wreck some part of the mechanism involved.

Fig. 5. Great Northern Railway, England. Two articulated cars showing the intermediate truck midway between the cars. Groups of five cars, similarly articulated, are in regular main-line service

There is, further, an irregularity in the angular rotation of the crank, with respect to the driving wheel, which creates a superimposed stress on the driving mechanism, and which may be the cause of very disagreeable vibration, should the natural period of the rotating mass involved happen to synchronize with the nodal points of angular variation. The effect of this irregularity in relative uniformity of rotation of the crank and wheel is more in evidence in some forms of side rod drive than others. The most severe case observed was on a direct connected locomotive with a V arrangement of connecting rods which ran with but little vibration, except at the critical speed, when a knock developed which sounded as if the crank shaft was broken, or being struck by a steam hammer. As this irregularity is due to the play in the bearings and the spring in the parts, it cannot be entirely eliminated in practical operation, but it may be minimized by maintaining the alignment and close adjustment of the bearings. It is obviously desirable to diminish the shock by cushioning as much of the rotating mass as possible.

Mr. H. Parodi, chief electrical engineer of the Paris Orleans Railway, in the *Revue Generale des Chemins De Fer* of March, 1922, has written of the vibratory characteristics of side rod drive and described the method he employed to improve the operation, by the introduction of springs, permitting angular movement between the mass of the motor armature and the crank shaft.

An attempt will be made to show graphically on the screen something of these characteristics of side rod drive. To better illustrate the action, the mechanism is assumed to be inelastic, the pin bearings of the rods are shown with exaggerated clearance, and the ordinates of the characteristic curves are greatly out of proportion. In reality, the value of these ordinates is dependent upon the working clearance in the bearings together with the inertia of the rotating masses and whatever may be their actual value, the character of the action calls for its consideration in the design of motor-driven side rod mechanism. Furthermore, the arc of action and the sharp angles of the characteristic curves as shown, would be modified by the spring in the connecting parts.

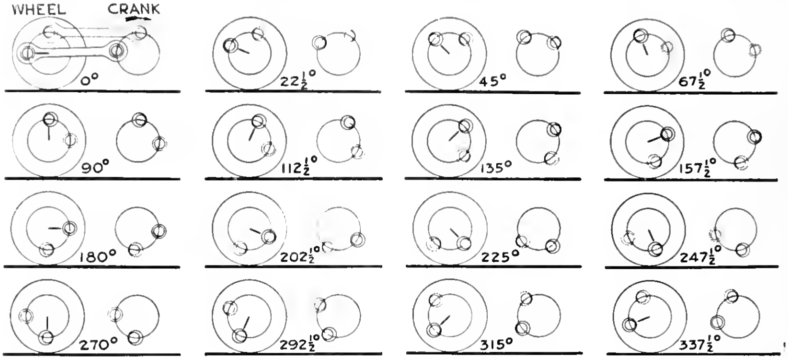


Fig. 6a. Diagram of Side-Rod Drive showing How Clearance in the Bearings Causes a Division of Load Between the Side Rods and Affects the Relative Angular Position of the Crank and Wheel

Fig. 6b. Curve showing Characteristic of the Change in Angular Position of the Crank with Respect to the Wheel

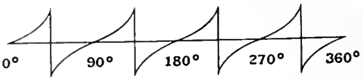


Fig. 6c. Curve showing Characteristic of the Angular Velocity of the Crank with Respect to the Wheel

There appears to be an increasing interest on the Continent in other methods of drive, requiring less attention and maintenance. The Paris Orleans Railway have been operating axle geared locomotives in their Paris Terminal for more than 20 years and have recently ordered 200 of this type for local passenger and freight service on their main line extension. Over 100 locomotives of similar type are being built for the Midi and the State railways. Locomotives with the same type of drive are also being built for the Spanish Northern Railway.

The electric locomotives on the Italian railways are mostly of the direct connected side rod type. The workmanship and finish of these locomotives is exceptionally fine, so good in fact from our point of view that we might consider it an extravagance. They are well maintained, are giving good service and many additional locomotives have been built from the same design.

The electrification of the railways in Switzerland has been very well carried out and they may well take pride in their construction and equipment. The Swiss railways have a variety of locomotives which are principally of the geared side rod type. The finish and workmanship of these locomotives is excellent, and they are very fine examples of geared side rod construction.

An interesting departure from side rod drive is a Swiss locomotive having the novel design of an outside geared drive, which is being given a thorough service trial with a number of locomotives. These locomotives have an inside frame the same as a steam locomotive, the motor being carried on the

Fig. 7. Italian State Railways. Direct-connected side-rod drive with Scotch yoke. Type originally built by the Italian Westinghouse Vado Ligure Works and later by other Italian manufacturers

Fig. 8. Prussian State Railways. Direct-connected side-rod drive with one motor through a vertical rod, A.E.G., Berlin

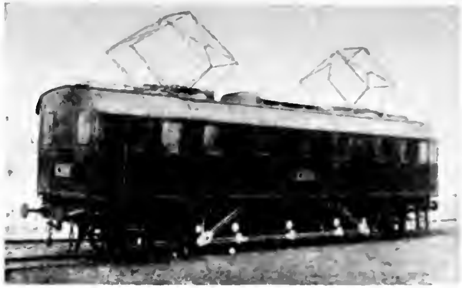


Fig. 9. Midi Railway, France. Direct-connected side-rod drive with two motors, C. F. T. H., Paris, and Swiss Locomotive & Machine Works, Winterthur

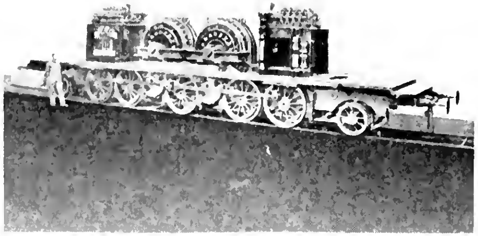


Fig. 10. Loetschberg Railway, Switzerland. Geared side-rod drive, Brown, Boveri & Co., Oerlikon Co., and Swiss Locomotive and Machine Works, Winterthur

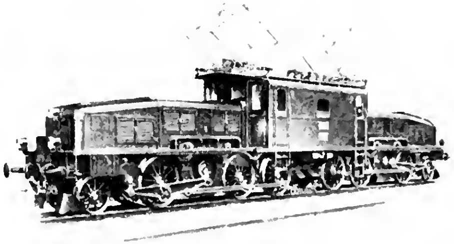


Fig. 11. Swiss Federal Railways. Geared side-rod drive; each of the jack cranks are driven by two motors. Oerlikon Co., and Swiss Locomotive and Machine Works, Winterthur

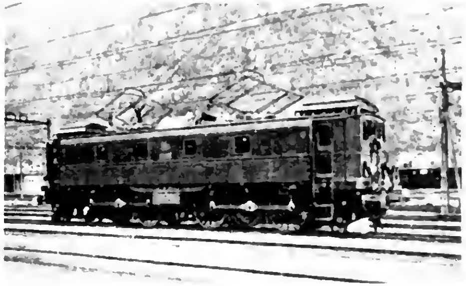


Fig. 12. Swiss Federal Railways. Geared side-rod drive. Two motors are connected to each of the jack cranks, Brown, Boveri Co., and Swiss Locomotive and Machine Works, Winterthur

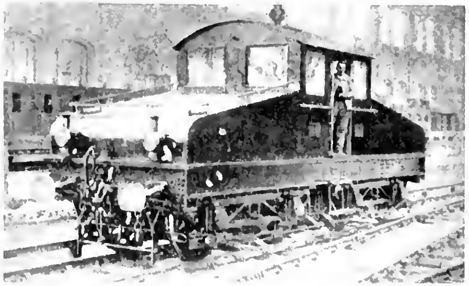


Fig. 13. Paris Orleans Railway. Axel geared drive. Originally built in 1900 for the Paris Terminal by the General Electric Co. and the American Locomotive Co., Schenectady, N. Y.

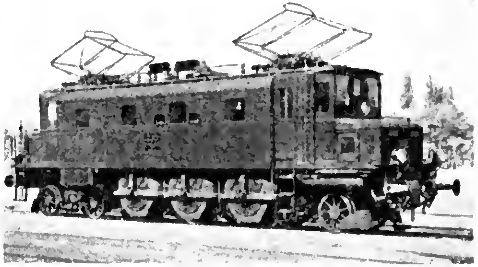


Fig. 14. Swiss Federal Railways. Outside geared drive. Built by Brown, Boveri & Co., Baden, and the Swiss Locomotive and Machine Works, Winterthur

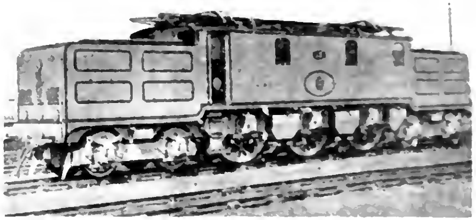


Fig. 15. North Eastern Railway, England. Geared quill drive. Designed by N.E. R. for 75 miles or more per hour. Metropolitan Vickers Co. and North Eastern Railway

frame directly over the driving wheel. The armature pinion is located beyond the outer face of the driver. The gear case is attached to the locomotive frame and is a strong structure provided with a pin in the center on which the gear revolves. The gear is carried about 3 in. from the outer face of the driver and within the gear is a system of balanced links, which engage with the two pins projecting from the driving wheel. These links are so designed as to provide for independent movement of the gear and driver in any direction while still maintaining their relative uniformity of rotation. This locomotive runs very smoothly without any characteristic vibration, and the more general use of this type of drive on the Swiss railways may reasonably be expected. These railways have also in trial service a number of locomotives with geared quill drive.

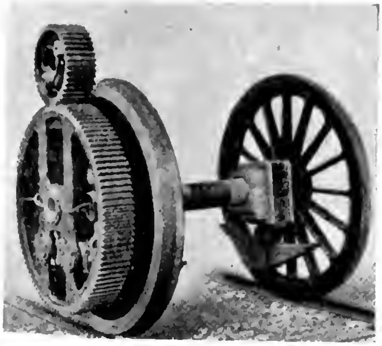


Fig. 16. Swiss Federal Railways. Outside geared drive showing location of gear and pinion with respect to the driving wheels

European motive power equipment is generally of more elaborate finish and gives the impression of being better maintained than is customary with us. An instance is recalled of two steam locomotives which were double heading on the London and North Western. One of these locomotives was built in 1897 and the other in 1867. They were polished and varnished with equal care and had every appearance of being of the same vintage, until one observed the date label, and that the older locomotive had only one pair of drivers while the other had two. As an illustration of the greater attention given to details, it is customary on many of European railways to equip both steam and electric locomotives with a speed indicating and recording instrument. The record obtained is very complete, showing the speed at all times during the run, distance covered, time of the run and the location and duration of the stops.

The braking equipment of European trains is quite different from our almost universal practice. Their passenger trains are equipped with power brakes of either the vacuum or pressure type and usually with two brake shoes per wheel. As there are several different braking systems in use, it is necessary in some instances to equip through cars, which run over different railways, with more than one system. In the trans-European service to Constantinople, it is said that each car has to be equipped with four different braking systems to conform with the regulations en route.

Power brakes are seldom used on the freight trains and some of the freight cars have no brakes whatever. In many of the freight yards there will be found wooden wedges, which are for the purpose of chocking the wheels to hold the cars in place. The hand brake attachment to the braking system is usually through a screw and nut, instead of the chain and brake staff we commonly use. In some instances the brakes are applied only by a lever extending along side. To handle freight trains on grades, where the brakes are necessary to control the speed, it is customary to provide a brakeman for every four cars. In ordinary freight movements the braking is done entirely with the locomotive.

The sliding contact for current collection from overhead lines is almost universal on the Continent, for both tram cars and locomotives. Two triangular tubes of brass or copper are used for the contact on many of the Italian three-phase locomotives, and triangular blocks of carbon are used on some of the direct current lines; but generally

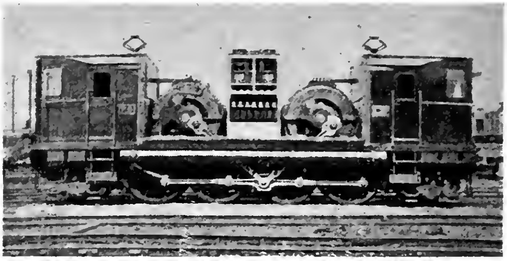


Fig. 17. Paris Orleans Railway. Locomotive with direct-connected side-rod drive. The motors have torsional springs between the armatures and motor cranks. Built by Cie Electro-Mecanique Le Bourget, and the Swiss Locomotive and Machine Works, Winterthur

for tram cars and single-phase locomotives the collector is an aluminum bow of U shaped section with a groove for lubricant.

In locomotive service it is the practice to use two of these bow collectors on each locomotive, and because of the soft material the pressure against the conductor is limited to about 8 lb. With this light pressure, some arcing might reasonably be expected and is observable when collecting from a single wire. In some places two conducting wires with interspaced hangers are used, which is better for current collection than a single wire, as it provides greater flexibility and doubles the collection contacts. Where the double wire construction had been used there was no observable arcing at the collector. While the aluminum bow serves its purpose well for collecting the 100 amperes or more for which it is used, it would not be suitable for collecting current of any great magnitude.

Collectors of this type would by no means serve for the Chicago, Milwaukee & St. Paul locomotives, on which the current ranges from 800 to 1200 amperes. The collector used with these locomotives has two separate, flat, copper contact surfaces, while the overhead system has double wire conductors with interspaced hangers. This provides four independent contacts in parallel, each of which are 4½ in. long, so that theoretically the aggregate contact is a line 18 in. long. The pressure of the collector against the conductor is about 30 lb. The relatively large amount of current taken by these locomotives is collected with no observable arcing, as the continuity of contact is well insured and the contact surface is of adequate capacity.

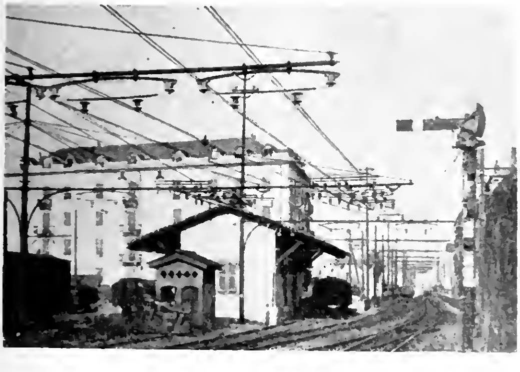


Fig. 18. Italian State Railways. View of overhead lines of three-phase system, showing long bracket arm construction and bow-shaped supports to facilitate the alignment of the conductors

Any appreciable arcing at the contact between the collector and conductor is unquestionably more destructive to both than the wear that occurs from mechanical friction. Continuity of contact must be maintained, if destructive arcing is to be avoided and the design of the collecting system should be such as will best ensure this continuity.

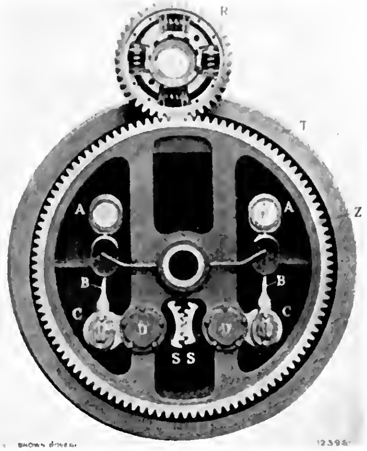


Fig. 19. Swiss Federal Railways. View of gear and pinion, showing arrangement of equalizing links, which connect at AA with pins projecting from the driver

After investigating the various systems of railway electrification, a number of the European countries have established regulations in favor of a particular system for the electrification of their steam lines.

France, Belgium and Holland have decided in favor of 1500 volts direct current. The overhead system of conductors will, presumably, be used in these countries with but few exceptions. There was some discussion in France as to whether 1500 volts should be the generated or the average voltage of the system. It was finally ruled that 1500 volts referred to the generated voltage, but that a maximum tolerance of 5 per cent would be allowed. There are no electrified railways of importance in Belgium and no projects under immediate consideration. In Holland an initial electrification is being undertaken between Leyden and The Hague, this being a portion of the main line that will ultimately be electrified between Amsterdam and Rotterdam.

England has also decided in favor of 1500 volts direct current, except in special cases, of which the London, Brighton & South Coast Railway is an example. This railway is partially electrified with single-phase and it is proposed to complete the electrification with this system.

It is presumable that a 1500-volt third rail will be quite generally used in England. The Lancashire and Yorkshire Railway have been operating over about 20 miles of third rail at 1200 volts with success, for some seven years. The North Eastern Railway have been operating 600 volts third rail for something over 15 years, and have a more recent electrification, with an overhead system at 1500 volts. The London and South Western Railway have a 1500-volt third rail under consideration. The South Eastern Railway, which runs near the Greenwich Observatory, are proposing to use two third rails with 3000 volts potential between them, but with the generating and motive power equipment connected in three-wire relation to the track, so that the voltage between each rail and ground will be only 1500 volts. The purpose of this double rail arrangement is to eliminate currents in the earth, which might affect the observatory instruments.

The principal railways in England, some twelve in number, radiating from London, have recently been consolidated into four groups, corresponding to the Northern, Eastern, Southern and Western portions of the country. The purpose of these consolidations is to better co-ordinate the service of the railways in each group, and to direct the transportation of the country more effectively and economically through four general Boards of Directors, instead of through the large number representing the individual railways.

There has been no official decision in Spain as to the system of electrification for their steam railways. There is in operation a short line equipped with the three-phase system. An important electrification on the Spanish Northern Railway, over a mountain division in the north of Spain, will soon be in operation with 3000 volts direct current.

Switzerland has standardized the single-phase system at 16⅔ cycles for their principal electrifications, and this system is being generally extended, although 1500 volts direct current is being used on some of the smaller railways. For other than single-phase railways, the standardized frequency is 50 cycles.

The Italian electrifications are almost exclusively three-phase, although there are several lines equipped with 600 volts and there is a recent installation of 4000 volts direct current. Consideration is being given to a thorough trial of 3000 volts direct current in the central portion of Italy, south of the present zone of three-phase operation.

Germany is continuing the use of single-phase for steam railway electrification, although it was stated that 1500 volts direct current would presumably be employed for heavy multiple unit and interurban service.

The subject of electric railway systems is under discussion in Sweden. The more important existing electrifications are equipped with the single-phase system at 16⅔ cycles. As the standard frequency for general purposes is 50 cycles, there appears to have arisen some question as to the expediency of generating and transmitting a particular frequency for the railways only. The more general utilization of natural resources and the better load factor resulting from diversity of use, would seem to indicate an economic advantage in favor of generation at the standard frequency with substation conversion into whatever form of electrical power the railways may require.

The economy in fuel obtained by modern steam power stations and the many available sources of hydraulic power have contributed to stimulate greatly the electrification of the steam railways in Europe. Government endorsement of the projects has also been helpful in financing these enterprises.

Table I, compiled from available records, will give an idea of the extent of railway

TABLE I

STEAM RAILWAY ELECTRIFICATION

	Route Miles	No. of Electric Locomotives
United States	1607	375
Switzerland	661	156
Italy	650	309
France	602	338
Germany	550	49
Austria	340	42
Sweden	237	44
Cuba	180	18
Africa	174	77
Chile	154	42
England	129	12
Canada	49	9
Spain	48	17
Japan	39	42
Norway	39	37
Mexico	30	10
Brazil	26	16
China	25	13
Java	25	5
Total	5565	1611

electrification throughout the world. It includes the steam railways which have been electrified or are in process of electrification, but not the steam railways on which multiple unit trains are being used exclusively, or electric railways which were not formerly operated by steam.

This is less than 1 per cent of the railway route mileage of the world. Conceding the efficacy of the steam locomotive for much of the world's service, there still remains a very large mileage which could be advantageously electrified. In the execution of this great undertaking we have many engineering and economic problems, the solution of which demands the cordial co-operation of all who are engaged in the furtherance of railway transportation.

Arc Welding of Cast Iron

PART I

By W. H. NAMACK

CHAIRMAN SUB-COMMITTEE ON ELECTRIC ARC WELDING OF CAST IRON, NORTHERN NEW YORK SECTION, A. W. S.

In our last issue a discussion was given of the general considerations that must be taken into account in the welding of cast iron. The composition of such iron was analyzed with regard to the influence which each of these components have on the weldability. The following article, which is an abstract of the first part of a paper delivered by the author at the fall meeting of the American Welding Society, presents further information relative to the investigation made by this society to determine the technique of welding cast iron by the carbon arc and by the metallic arc processes, the latter with and without studs. The succeeding installment will detail results of an extensive test which was conducted to obtain additional data on the metallic arc welding of cast iron without studs.—EDITOR.

There are two fundamental methods of arc welding cast iron; viz., by the carbon arc, and by the metal arc. The latter may be divided into metal arc welding with studs and metal arc welding without studs. Each type of welding mentioned will be treated in the order named.

CARBON ARC WELDING OF CAST IRON

Carbon arc welding is used over a considerable range of application and somewhat resembles the oxyacetylene method, one difference being the way in which the heat is produced. Difficulties are encountered in welding thin sections by the carbon arc process. In welding cast iron with the carbon arc, the casting is sometimes preheated. When this is done, the same precautions must be used (both during heating and cooling) as in the case of gas welding.

Obviously it would be desirable if the weld area could have the same composition and characteristics as the original cast iron. With a view to approaching this result, the conditions under which the weld is made should preferably be similar to those employed in making cast iron and the same precautions taken with respect to slow uniform cooling to allow for precipitation of the carbon from the combined state, in which it exists in the molten case iron, into the graphitic state in the finished weld. The welded part will be machineable to the extent to which this result is attained. Welds of this kind are possible with the carbon arc method, if the precautions suggested in the following paragraphs are followed.

Preheating

Unless the work is very small and of simple form, it should be preheated to a "dull red" heat to minimize shrinkage stresses. Where the work is complicated, slow heating is necessary. Uneven heating may cause warpage and introduction of stresses.

Manipulation

The arc is applied to the edges to be welded until the iron commences to melt. Then the bottom of the V is melted down, applying during the fusion a little flux or scaling powder with the heated end of the filler rod. It is important that the two edges to be joined should melt at the same time. Metal from the filler rod should not be added until the bottom of the V has been filled by metal from the sides. When ready to add metal, the end of the filler rod should be placed in the melted metal of the weld and the arc played on both the rod and the weld so that the metal runs together. The rod should be dipped in the sealing powder as often as is necessary and the filling in process continued. However, too much sealing powder should not be added at one time. Only just enough is needed to make the metal run freely. The weld should be made in steps. If too much metal is added in one place it is likely to run into the bottom of the V, and unless the welder is experienced and careful this will cause a "cold shut" and the weld will be defective. As the filling progresses, the operator should satisfy himself that the metal is welded at both sides.

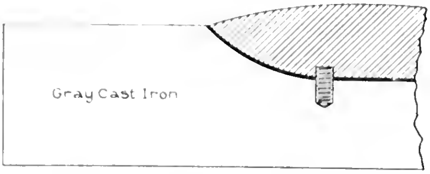


Fig. 1. Illustration of a Single Stud and Its Location Relative to the Hard Zone

The melting of the filler rod should take place as much as possible in the molten bath in the bevel by plunging in the rod and then playing the arc all around. This method should always be used for great thicknesses.

Certain essential manipulations are sometimes difficult to execute. For example, the fluidity of the metal when melted does not permit of making vertical welds. It is therefore desirable to arrange the line of welding as nearly horizontal as practicable, although this is difficult with certain shapes and sizes of pieces to be welded.

The fluidity of molten cast iron makes it necessary in certain work suitably to surround or support the edges to be welded in order to prevent the metal from flowing away.

Filler Rod and Flux

One advantage of the carbon arc process is that the filler rod can be of cast iron, thus permitting of actually depositing cast iron in the weld. This procedure will, when a suitable flux is used, tend to produce the same general characteristics as those of the base iron. To the extent to which this is effected, the subsequent machining of the parts will be practicable.

A good flux can be made of a mixture of equal parts of carbonate of soda and bicarbonate of soda. Washing soda is the name commonly given to a somewhat impure carbonate of soda, while bicarbonate of soda is ordinary baking soda. There is no necessity that either should be in a chemically pure state. The action of the carbonates is to combine with the oxygen in the slag, releasing the iron and allowing the oxygen to pass off in the form of carbon monoxide or carbon dioxide.

With cast iron, the oxide formed is lighter than the melted metal and does not flow at quite so low a temperature. The slag which forms on the surface of the iron therefore tends to hold the melted metal in place. Sealing powder should be added by dipping the rod into the powder only when the metal does not flow well and no more should be used than is necessary.

When using a flux in welding cast iron it will be noticed that, as soon as a small portion of the flux is put on the melted iron, the surface of the metal becomes clear and mirror-like, thus making a good weld possible.

Annealing

After the weld has been completed, it is desirable that the cooling should be as slow as possible. For articles which have been preheated it is best to replace them in the oven and cover them completely with asbestos or some other non-conductor, so as to avoid local cooling.

Many articles of cast iron, although they have been properly welded, break or crack in cooling, either in the line of welding or elsewhere, owing to a failure to observe such precautions as shall prevent local contraction.

When a coke or charcoal fire has been used for preheating, the piece welded should be completely covered with cinders or charcoal; refractory bricks or sheets of asbestos should be placed on the sides and underneath, so as to avoid all draughts of cold air, and the article should be left until it is completely cold. Sometimes it is necessary to allow twenty-four hours for cooling.

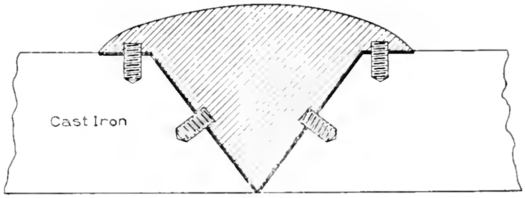


Fig. 2. Cross Section of a Studded Joint

METALLIC ARC WELDING OF CAST IRON

Much cast iron arc welding is now done with the metallic arc process. In this process an arc is drawn between a metal wire electrode and the base metal, the filler metal being supplied by the melting of the electrode. In this respect, the process is exactly the same as that employed in the metallic arc welding of steel. However, owing to several circumstances amongst which may be mentioned the high percentage of impurities contained in cast iron, its brittleness, low strength, and comparatively low melting point, the making of a dependable cast iron weld is very much more difficult with cast iron than with mild steel.

Penetration

It is extremely difficult to obtain good fusion of the filler metal with the cast iron, or as it is commonly termed, good "penetration." This is particularly true of gray iron, white iron being distinctly easier to weld. The greater difficulty of welding gray cast iron seems to be due partially to the flakes of free graphite present. These tend to separate the filler metal from the cast iron and also tend to separate the grain of iron from each other.

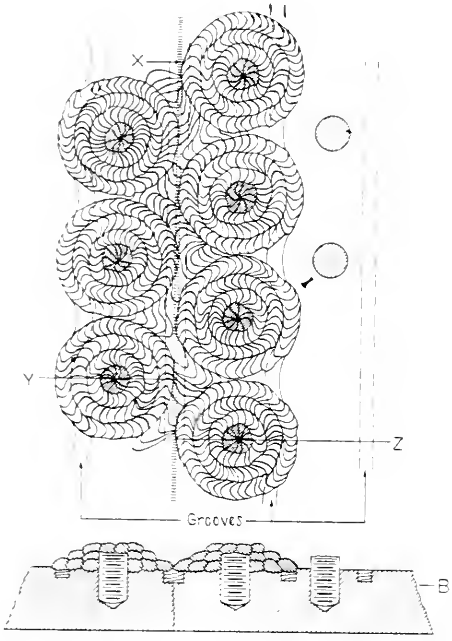


Fig. 3. Procedure in Welding a Studded Joint in Which Square-section Grooves Have Been Cut to Protect Against Shrinkage Strains

Carbon Content

In welding cast iron by the metallic arc process, the surfaces to be joined are melted by the heat of the arc between the electrode and the base material. In gray iron, these surfaces consist of iron which contains carbon in both the combined and uncombined states. As soon as the heat of the arc is removed, the melted iron solidifies very quickly, owing to its proximity to the comparatively cold mass from which it has been melted by the arc and further owing to its being exposed to currents of cold air. Naturally this portion of the metal which has been made liquid and has cooled quickly is very hard, and furthermore any uncombined carbon which is brought to the surface also has a deteriorating effect on the weld, since it acts as a separator between the deposited metal (assuming that the filler metal is deposited in layers) and the metal which was melted on the surface of the cast iron.

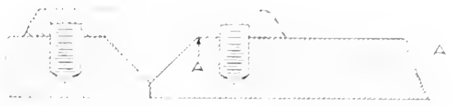


Fig. 4. Method of Welding a Studded Joint Where the Carbon is in Condition to Produce Good Fusion Between the Casting and the Weld Metal

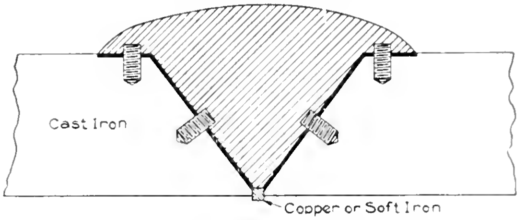


Fig. 5. Cross Section of a Studded Joint in Which a Strip of Copper or Soft Iron Has Been Inserted

Oxidation

When iron is brought to a high temperature in the presence of oxygen, as in welding, oxidation of the metal takes place. When it becomes oxidized the oxide segregates out and being in a granulated state it will, if trapped in the weld, cause a weakness and make it impossible to fuse the added metal to it. This difficulty may be overcome if due care is exercised in removing this surface oxide by means of a stiff wire brush.

Shrinkage

As the metal in a weld cools from the molten state, its volume decreases considerably. For example, the contraction of cast iron in cooling from its melting point to ordinary room temperature is approximately one per cent. This amounts to one-eighth of an inch per foot of length. Consequently, if the two parts being welded together are not free to move in response to the forces set up by the contraction of the weld metal, very severe stresses will result. As cast iron has practically no ductility, these stresses may break the casting, unless they can be relieved by the stretching of the filler metal.

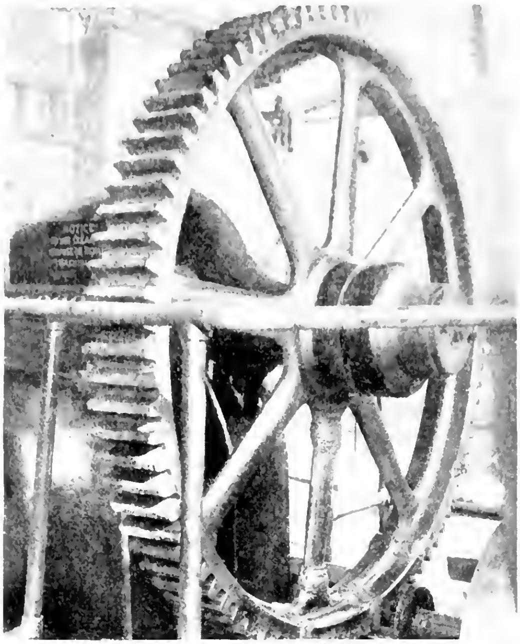


Fig. 6. Gear Repaired with Bare Electrodes Using 150 Amp. Each Weld Reinforced Approximately $\frac{3}{16}$ in. at the Center of the V Groove; Cost $13.00

The situation is complicated by the fact that if steel is used as a filler metal, as is ordinarily the case (i.e., if a steel electrode is employed), the shrinkage of the filler metal is from 50 to 100 per cent greater than that of the cast iron itself, since the contraction of steel, during cooling, is from 1.5 to 2 per cent. Therefore, there is a tendency for the filler metal to slide over the iron, often resulting in a break at the line between the filler and base metals.

Shape of Casting

The shape of the casting must also be considered in connection with shrinkage. If a heavy section is heated up by welding and if its expansion, when heated, throws a stress on a lighter section elsewhere in the casting, that lighter portion is liable to fail. Again if a light and heavy section are heated equally and then cooled, the lighter section will cool (and consequently contract) faster than the heavy section and a break through the lighter section is liable to occur.

Use of Steel Studs

A very successful method of overcoming troubles due to shrinkage consists in employing steel studs screwed into the cast iron, the filler metal being welded to them. These studs pass through the brittle layer of iron at the weld and transfer the stresses to the mass of metal back of the weld.

Obviously the use of studding entails considerable expenditure of time and labor, owing to the necessity for drilling and tapping the holes and inserting the studs. It appears, however, to be the consensus of opinion of arc welding specialists that studding should at the present stage of our welding experience be employed when the cast iron parts are not free to adjust themselves in response to the contraction stresses set up during cooling.

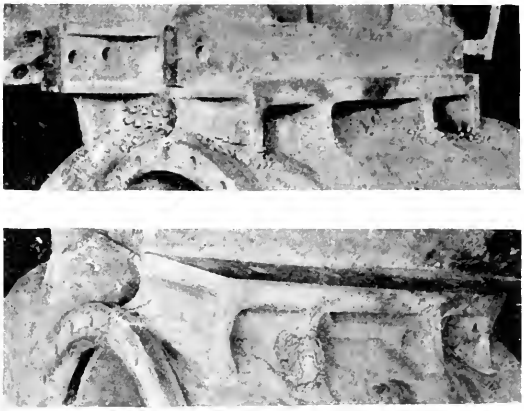


Fig. 7. Cylinder Repaired with Bare Electrodes Using 175 Amp. Quarter-inch studs were used without V-ing out the work

In applying the studding method it is general practice to so chip out the crack to be welded as to form a V. Studs are then inserted in one or more rows, either in the faces of the V or alongside it, or at both these locations. Studs on one side of the weld are placed opposite the corresponding studs on the other side. If, however, more than one row of studs is used, the studs in adjacent rows on each side are usually staggered. The stud holes are drilled and tapped with a bottoming tap. The studs are screwed in tight, completely filling the hole for a depth of about one and one-half to two times the diameter of the stud. It is convenient to use rods threaded for their entire length. These are screwed in tight and are sawed off at a distance of $\frac{1}{8}$ in. or more above the surface of the work, the precise distance depending upon the size and shape of the weld.

The determination of the size and number of studs to use is a matter of calculation and experience. The combined strength of the studs should be sufficient to develop the full strength of the cast iron. As steel has approximately four times the strength of cast iron, the ratio of the total cross-sectional area of the studs on one side of the weld, to the cross-sectional area of the cast iron, should be approximately one to four. The technic of the process is ordinarily better when large studs are employed for large sections and smaller studs for smaller sections.

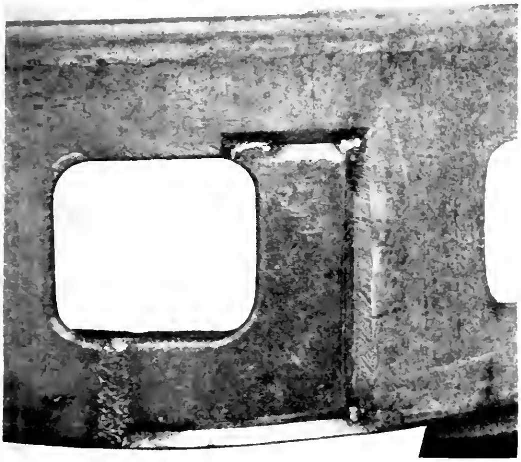


Fig. 8. Welding a Steel Patch to Repair a Cast Iron Break

The usual welding procedure is to first weld around each stud forming a cone-shaped pad of deposited metal and to then weld from pad to pad until the entire face of each side of the V is covered with steel filler metal. Finally, the space between those faces should be filled in by welding. It is sometimes recommended that the filling in between faces be done by laying in beads along the length of the weld, rather than cross-wise, with the idea that this may reduce the contraction stresses across the weld. This method is liable to reduce somewhat the tensile strength across the filler metal itself but as its strength is ordinarily much higher than that of the cast iron base, a small reduction is not serious.

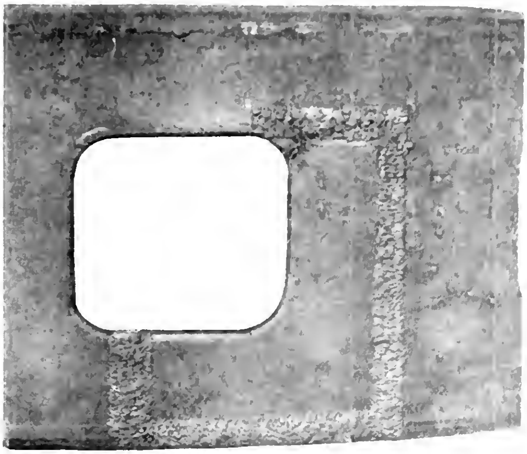


Fig. 9. Completion of the Repair Work illustrated in Fig. 8

Hardness at Weld

When cast iron is welded by the metallic arc process, without preheating, there is usually a layer of extremely hard metal at the junction of the filler and base metal. This is sometimes so hard as to be unmachineable, except by grinding. This hard layer is ascribed principally to the formation of what is known as "white iron."

This white iron is formed when the molten surface layer of cast iron is chilled by the cold mass of metal lying back of it. In white iron, which is extremely hard and brittle, the carbon is held in solid solution. In this form the carbon is present as combined carbon.

Furthermore a portion of the steel filler metal, while molten, absorbs some of the carbon from the molten cast iron, becoming high carbon steel and is also quickly cooled, giving in effect a layer of quenched high carbon steel.

It is suspected that the formation of nitrides in the weld may also be a contributory cause of the extreme hardness. In fact it appears that the extreme hardness often experienced is due to something more than simply the formation of white cast iron. Methods of research to determine the true cause and possible methods of overcoming this hardness are of much importance and have been considered by the Committee.

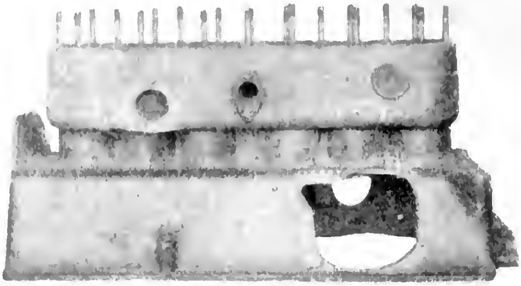


Fig. 10. Break in Cylinder Block Studded Preparatory to Welding

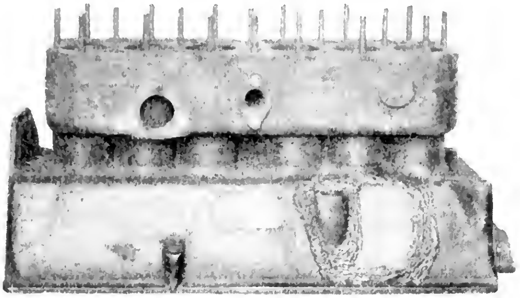


Fig. 11. Cylinder Block Shown Above After Being Welded

Preheating and Annealing

The best method of avoiding the hard zone from the standpoint of metallurgical results would seem to consist in preheating the casting before welding, or annealing it after the completion of the weld. By either preheating or annealing, if properly done, the hard zone can usually be avoided, without prejudice to the quality of the weld. The unfortunate circumstance is that either preheating or annealing is expensive and requires special equipment. It necessitates placing the casting in a furnace or some equivalent process and may result in warping the structure.

If no furnace is available, a temporary one may be built of fire bricks and the casting heated by a coke or charcoal fire. Care should be exercised to see that all parts of the casting are heated uniformly and it is best to heat it rather slowly. For preheating, a temperature of about 500 deg. C. (corresponding to a "dull red" heat) should be employed. The weld should be made promptly and the casting allowed to cool down very slowly in the furnace. If the casting has been heated with a charcoal or coke fire it should, while cooling, be covered with ashes and embers.

For annealing after welding, which is desirable if the very best results are wanted, the casting should be heated to a "red heat" (about 850 deg. C.) and then allowed to cool very slowly in the furnace.

Inserting Copper Strips

When only one side of a weld need be machineable, the following practice is sometimes adopted. The break is V'd out, with the apex of the V on the side that must be soft. Then a strip of copper is laid on the V and peened in. The steel filler metal is deposited in the V above the strip of copper. The copper filler is of course readily machineable.

Reversed Polarity

In ordinary metallic arc welding of *steel*, the work is connected to the positive terminal of the welding current supply source and the electrode to the negative. As considerably more heat is generated at

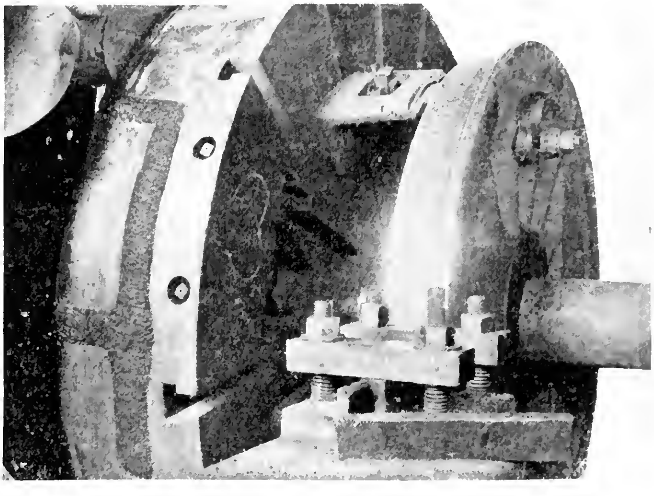


Fig. 12. Large Lathe Chuck Repaired with Bare Electrode using 175 amp., Cost $21.00

the positive end of an arc than at the negative, it has been proposed that in the welding of cast iron the polarity be "reversed," making the work negative and decreasing the temperature at the point of application of the arc. However even though the local temperature is decreased, a certain amount of the iron must be melted in order to obtain a weld and chilled iron is bound to result. On the basis of this reasoning "reversed polarity" should not be particularly effective in preventing the hard zone. Nevertheless some welding people of wide experience claim that softer welds are obtained in cast iron welding when "reversed polarity" is employed.

Special Electrodes

Electrodes of a wide variety of compositions and with various kinds of fluxes and some with flux coverings have been recommended and used for welding cast iron. The Committee is not prepared to say how effective these electrodes are, nor which is best.

Nickel electrodes are quite widely used in filling in blowholes in castings, for example, in automobile cylinders. Nickel possesses the advantage of not absorbing carbon from the cast iron. Hardness is thus avoided and a machineable joint is obtained. However, there is liable to be a small zone of chilled cast iron around the joint. It would appear that nickel should not be employed in a weld which will be placed in tension or shear.

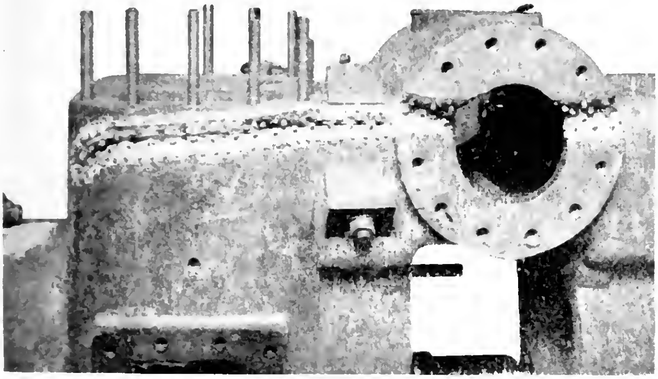


Fig. 13. Casting Prepared for Welding by the Studded Joint Method

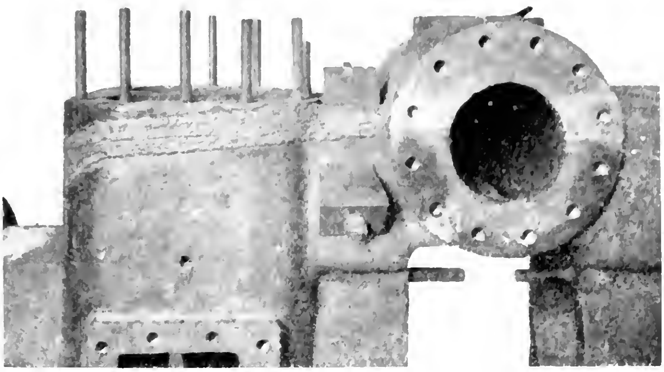


Fig. 14. Finished Welding Repair of the Casting Shown in Fig. 13

The Committee found that joints made with a nickel electrode using reversed polarity were not dependable as the filler metal consisted mainly of blowholes and gas pockets.

Phosphor Bronze electrodes are reported to have been employed with some success in producing machineable cast iron welds.

Monel Metal and other copper nickel electrodes are said to give a soft weld in cast iron and one of much strength. However these, electrodes are relatively expensive and it is believed that the deposited metal is apt to contain gas pockets. Consequently where these electrodes are employed, it is general practice to use them only on the first and last layers, or at places where holes are to be drilled. The remainder of the filling may be done with steel.

(To be continued)

Ten Years of Progress in the Design of Safe Tanks for Large Transformers

By W. S. Moody

Engineer Transformer Engineering Department, Pittsfield Works, General Electric Company

Mr. Moody tells of the development of the conservator type of transformer. He shows that the use of inert gas to eliminate explosions and the "sludging" of the oil was considered and tried out at an early date. These ideas were later abandoned for the conservator principle which keeps the transformers filled with oil constantly.—Editor.

In the October, 1919, issue of the Review the writer, under the heading "A New Form of Tank for Static Transformers," described the conservator type of transformer and the results of the three years of experience with this type.

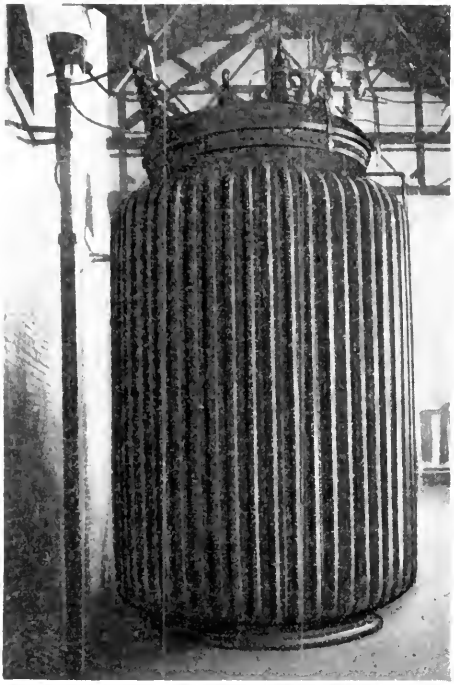


Fig. 1. Original Installation of Transformer Using Inert Gas

The continued practical success of the original construction and refined improvements thereon during the past 3½ years, applied to a total capacity of over 5,000,000 kv-a. of such transformers now built, fully justifies the optimistic view taken of the value of this construction.

This extensive use of the construction, and certain recent publications in the technical and daily press regarding a possible alternate form of construction, will make some remarks regarding the history of this development of interest to many Review readers.

Early in 1914, the great increase in the demand for large transformers suitable for installation out of doors, without protection from the weather, caused the engineers of the Transformer Department to study very thoroughly the problem of making the tanks of such transformers absolutely weatherproof.

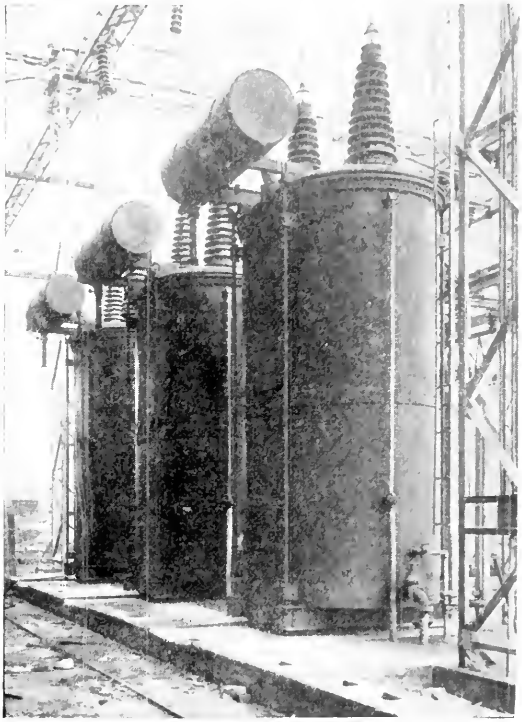


Fig. 2. Installation of 5000-kv-a. 140,000-volt Single-Phase Transformers with Conservators. Consumers Power Co., Battle Creek, Michigan

To so make the joints between the cover and tank and the numerous joints necessary between bushings, oil gauges, manhole covers, breathers, etc., reliably weatherproof, was not a simple matter. It was also realized that however well these features might be designed and built trouble from leaky joints might occur, as most of these joints must be remade at the time of installation.

Efforts were therefore made not only to incorporate simple and reliable methods for making these joints, but to find a construction that would immediately indicate any defect in them. One of the most promising methods appeared to have the air in the top of the transformer under slightly greater pressure than the atmosphere with a suitable indicator to show if any air was escaping. To this thought was added the idea that instead of air under slight pressure, an inert gas might be used, thereby avoiding any possibility of an explosive mixture in the tank.

Fig. 3. Installation of Conservator-Type Transformers at the Vacaville Substation of the Pacific Gas & Electric Co. Single-phase Auto Transformers of 16,667-kv-a output to transform from 200,000 to 100,000 volts

An appropriation to test the practicability of these ideas was obtained early in 1914, and factory tests were so satisfactory that in 1915 two orders were taken, one for 750 kv-a. transformers for the Remington Arms Company, and one for 5000 kv-a. units for the Narragansett Electric Company. With the customers' consent it was planned to give this construction a service test on these transformers.

The installations were made in March and May, 1916. CO_2 gas was used because it can be so easily purchased almost anywhere and a small "gasometer" was designed and used to maintain the slight internal pressure on this gas. The method was found quite practical, only four or five rechargings per year of the small gasometer being necessary.

Patent No. 1,326,049 was granted to a General Electric Field Engineer, Mr. F. C. Green (now deceased), covering this combination of transformer, inert gas, and gasometer.

Fig. 1 shows, rather poorly, the installation of the 5000 kv-a. transformer at Providence, R. I., with which this invention was tested out for some six months in 1916.

The method would undoubtedly have been used extensively by the Company from that time on had not a still better method of accomplishing all the desired results been found, largely as a result of these experiments.

These efforts to reduce the loss of inert gas in these transformers to a minimum led to simple and reliable methods being found to eliminate any leakage; there was no longer, therefore, any necessity for any gas within the transformer, for such a tank could, with safety, be completely oil filled and kept under a slight pressure from an elevated reservoir partially oil filled. Thus these experiments with the inert gas led directly to the present "conservator" construction—a simple and safer construction.

This construction, as stated in my 1919 article, was first given a service trial in 1916, at Laurinsburg, N. C. The construction has been repeatedly simplified and improved as to details, and today accomplishes all its duties with utmost reliability.

Studies in the Projection of Light

PART III

CHARACTERISTICS OF A PARABOLIC MIRROR AND SPHERICAL SOURCE OF LIGHT

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

In the first installment of this series a description was given of a simple and practical method of optical analysis as applied to the reflection of light from a paraboloid (parabolic reflector). In Part II analysis was made of the reflection of light from parabolic cylinder (parabolic trough) and ellipsoidal reflectors. In the present installment an explanation is given as to why the filament of a projector incandescent lamp can be treated as a spherical source when the lamp is mounted in a reflector of the conventional parabolic proportions. The characteristic formation of the beam is next discussed with reference to the increase of central intensity with distance, the inverse-square region, the testing distance for central intensity, and the width of the crest of the beam.—Editor.

The Spherical Source as a Substitute

One of the goals toward which the designers of incandescent lamps are striving is the production of an incandescent filament of spherical form. The goal seems to be far in the future, and can be seen only with the eyes of optimism; but there is a certain physical relation in the incandescent searchlight or floodlight that brings the final result in beam formation even now measurably closer to the desired end. This relation is between the mirror and the light source, and it applies particularly when the mirror is deep in proportion to its diameter.

Concentrated filaments in lamps designed for projection service have several forms. The wire is first wound into a close spiral and this spiral is then bent into loops that are held as close together as seems safe considering the voltage difference between the various parts of the filament. The filament arranged in this manner has but little outward resemblance to a sphere, but we must consider what takes place when it is used in connection with a mirror that partially encloses the lamp. There is a rule of geometrical optics that, while seldom found stated explicitly, might be worded as follows:

"Each section of a simple lens, or mirror, forms an image whose angular size and proportions are identical with the angular size and proportions of the object as viewed from that section." Thus if the source is a ring type filament, which is a more or less complete circle, and the plane of the ring is perpendicular to the axis of the mirror, the beam from the center of the mirror will have an annular form with an open side corresponding to the open side in the filament. A section of mirror to one side of the filament and in its plane will project a narrow vertical beam; a top section of mirror will project a narrow horizontal beam. These two sections alone, if the remainder of the mirror is covered, will project a beam that has a cross-shaped section. But if the entire zone containing these two sections is active in reflecting light, then there will be a multitude of crossing sections that will build up a perfectly round beam that has its greatest intensity in the center and tapers off gradually to a round outline. This beam bears no outward resemblance to the form of the filament, and while it is an extreme case it well illustrates how the mirror may influence the beam formation.

Mirrors used with incandescent lamps are in a great majority of cases of considerable depth, and the resultant beam is composed of a multitude of the filament images that vary in size and proportion, and it is solely due to the resulting blurring out of sharp images that we can in our mathematics substitute a spherical source for the actual source and then by computation arrive at the approximate facts. It will be readily appreciated that a filament that is even roughly spherical in outline will be better represented by the substitute source, and that a shallow mirror which has, so to speak, a single angle of view will give a sharp image for which we can find no satisfactory substitute. However, fortunately for the simple theory of the subject here presented, a great majority of incandescent units have deep reflectors in which the phenomena of multiple images and varying perspective have full sway.

Increase of Central Intensity with Distance

Every searchlight or floodlight has a critical point on the axis of the beam beyond which we can compute illumination with certainty, and short of which there always exists much doubt. It is important to know where this point is located, and what is the geometrical structure of the beam up to this point. It may seem somewhat strained to speak of the "geometrical" structure of the beam, but the term is fully justified by experimental facts; and using the simplest kind of geometry the entire beam may be analyzed by anyone willing to take the trouble. The analysis here presented does not cover all the ground, but only that part which seems of prime importance and necessary to know if one is to get the maximum benefit out of the material and equipment now available.

In Fig. 17, two sections P_1 and P_2 of a parabolic mirror are shown reflecting two images of the spherical light source located at the focal point of the mirror. At increasing distances the two images A_1 and A_2, which in this case are circular, will touch as they come into contact with the extended axis of the mirror; and at this point all of the mirror within the zone through P_1 and P_2 will be active; that is, it will reflect light through this point of contact. All the area outside of P_1 and P_2 will be inactive in reflecting light to the axis at this particular distance L_0, and the apparent beam strength is therefore

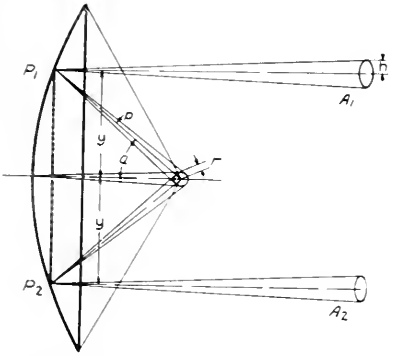


Fig. 17. Elemental Images of Spherical Source as Projected by a Parabolic Mirror

$$I = \pi\ Bmy^2 \text{ candles} \qquad (40)$$

where B is the brilliancy of the source in candles per square inch; m is the coefficient of reflection of the mirror; y is the radius in inches of the outer edge of the active area.

It should be noted that the beam intensity is proportioned to the projected area of the mirror and not to the surface area. Also, the distance L_0 should be measured from the edge of the active area, and not from the plane passing through the edge. This latter point is of small importance because the difference between measurements of L_0 made from the center and edge is very small and may be neglected.

The radius h of the image A_1 is proportional to the radius r of the source, is also proportional to the distance L_0, and inversely proportional to the radius vector p from the focal point to the point P_1 on the mirror. Therefore

$$h = \frac{12\ r\ L_0}{p} \text{ inches} \qquad (41)$$

where L_0 is expressed in feet and the other dimensions are in inches.

Rearranging, we have

$$L_0 = \frac{h\ p}{12\ r} \text{ feet} \qquad (42)$$

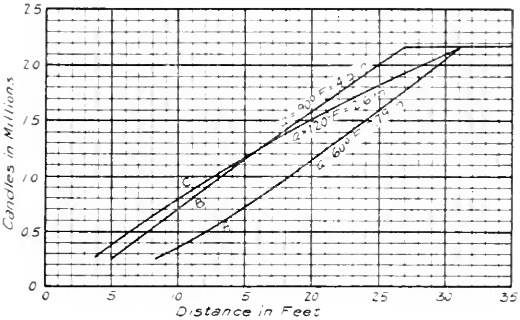


Fig. 18. Increase of Central Intensity with Distance from Parabolic Mirror 18 in. in diameter; Spherical Source 0.5 in. in diameter

and at the point of contact of the image A_1 with the axis, we have

$$h = y \text{ inches}$$

$$= 2\ F\ tan \frac{a}{2} \text{ inches} \qquad (43)$$

Therefore, in terms of F, r and a,

$$L_0 = \frac{F^2\ tan \frac{a}{2}\ sec^2 \frac{a}{2}}{6r} \text{ feet} \qquad (44)$$

or, in terms of F, r and y

$$L_0 = \frac{y(4F^2 + y^2)}{48\ F\ r} \text{ feet} \qquad (45)$$

and in terms of F and a the intensity on the axis is

$$I = 4\pi\ Bm\ F^2\ tan^2 \frac{a}{2} \text{ candles} \qquad (46)$$

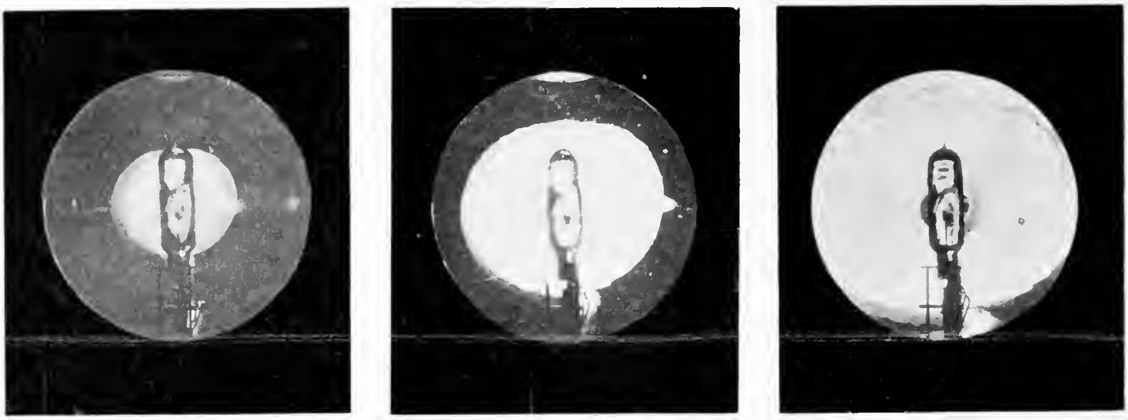
or, in terms of y

$$= 4\pi\ Bm\ y^2 \text{ candles} \qquad (47)$$

These equations give the desired relations between the axial intensity and the distance

L_0. In Fig. 18, data from equations (44) and (46) are plotted for three mirrors 18 in. in diameter equipped with a spherical source of 0.25 in. radius. The brilliancy of the source is 10,000 candles per square inch and the coefficient of the mirror is 0.85.

Mirror *A*, Fig. 18, has a focal length of 7.79 in. and a maximum value of 60 degrees for *a*. For mirror *B* the dimensions are 4.50 in. and 90 degrees, and for *C* they are 2.60 in. and 120 degrees.



Figs. 19, 20 and 21. Eighteen-inch Searchlight Mirror Images of Spiral Filament seen from distances of 9.6, 13.4, and 32 feet respectively along the axis

The three mirrors having equal plane areas give equal maximum intensities, but they approach the maximum in three different manners, and arrive at the maximum at two different distances. Equation (44) may be written

$$L_0 = \frac{y^2}{12r\,sin\,a}\text{ feet} \qquad (48)$$

In case the radius y of the mirror is constant and the angle a varies, the lowest value of L_0 occurs when $sin\ a$ is a maximum, that is, at $a = 90$ degrees; and for angles equally above and below 90 degrees; for example 60 and 120 degrees, the values of L_0 are the same.

Equation (44) shows that if the angle a is constant the value of L_0 varies as the square of the focal length. The focal length of one series of standardized mirrors varies from 7 to 25 in.; and this series alone calls for a variation of 13 to 1 in the testing range, so that this matter of minimum range for full central beam intensity is of considerable importance.

In Figs. 19 to 21 the growth of the active area of a mirror is shown for three points along the axis. The filament was a short helix, and in Fig. 21 the turns of wire may be counted and the hole through the helix appears as a black spot in the center of the mirror. This inactive area introduces a peculiar feature. The beam increases in strength until at 31 ft. the maximum is reached when the active region reaches the edge of the mirror. At greater distances the inactive center increases and therefore there is no inverse-square region. The dark center does not increase indefinitely but comes to a maximum area as outlined by the diagonals through the hole in the helix. There is thus a rise of intensity to the L_0 point, then a slight decrease to a practically constant intensity at a distance several times L_0. If the diagonals through the helix strike the mirror at radius y_1, then the limiting central intensity becomes

$$I = \pi\,Bm\,(y^2 - y_1^2)\text{ candles} \qquad (49)$$

The Inverse-square Region

Let us designate as L_0 the point on the axis where the beam reaches full intensity. This L_0 point is of importance because it is one of the limits of a region in the beam where the illumination can be computed by applying the law of inverse squares. The candle intensity within this region is constant and the illumination varies inversely as the square of the distance back to the mirror. It has happened several times to the writer's knowledge that some one has discovered this inverse-square region, or region where the entire mirror is active, and has then been deceived into taking the L_0 point as the virtual origin of light. In Fig. 22 the limiting rays from the center and edges of three 18-in. mirrors having foci of 7.79, 4.50, and 2.60 in. are drawn to show the outline of the entire beam and the outline of the inverse-square region, which is shown shaded. Between the edges of the beam and the edges of the inverse-square region the inverse-square law never holds exactly, but at sufficient distance the disagreement is small. Mention will be made of this feature later.

Testing Distance for Central Intensity

When a projector is to be tested for beam intensity there are several preliminary matters to be settled before the test can proceed. Thus, the distance must be sufficient for the beam to come into approximately final form. This is essential for if the examination is not made at the proper distance, the distribution of intensity will depend upon the distance and the addition of this factor will add to the difficulties, which are always numerous enough under the best conditions, and make even a simple comparison of projectors a very uncertain matter. On the other hand, even if space limitations will permit it is not always wise to go to extreme distances on account of the absorption and scattering of light by the atmosphere.

The relations between the minimum distance at which a beam develops full intensity and the dimensions of the mirror and light source were given in equations (44), (45) and (48) in a form that contained the radius r of the source. The angular width of the beam is usually easy to determine in a finished unit, whereas the average effective radius r of a filament is difficult to measure, and it is therefore a great convenience to be able to find the value of L_0 from the beam width rather than from the filament.

Calling the total angular width of the beam C degrees, we have

$$L_0 = \frac{458\, sin\ a}{C(1+cos\ a)^2}F \qquad (50)$$

which is plotted in Fig. 23 for various beam widths between 10 and 70 deg., and in Fig. 24 for mirror angles up to 140 deg. These values are of course the least distance that can be used, and where circumstances allow should always be exceeded by about 50 per cent.

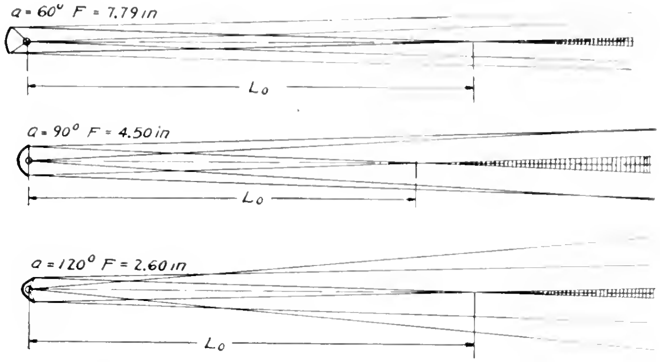


Fig. 22. Region of Inverse Squares in Beams of Light Projected by Parabolic Mirrors from Spherical Sources. The shaded section shows the inverse-square region (which has its zero point of linear measurement at the searchlight) within which the illumination follows the law of inverse squares

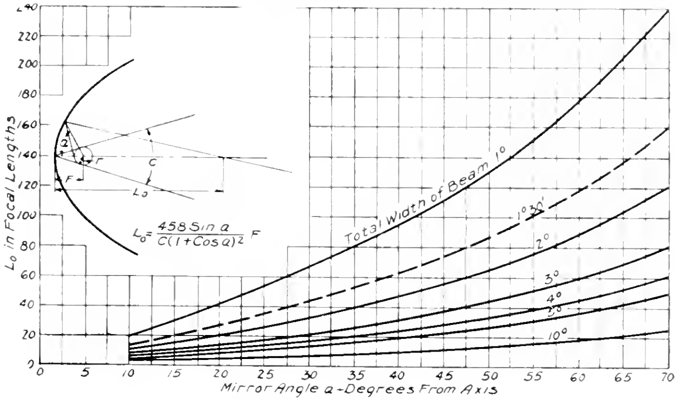


Fig. 23. Minimum Testing Distance for Central Intensity of a Beam Projected by a Parabolic Mirror from a Spherical Source. Range, angle *a* from 10 to 70 deg.

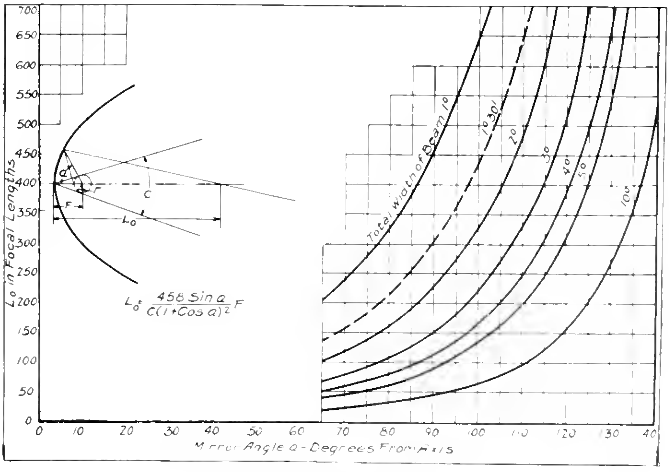


Fig. 24. Extension of the Curves shown in Fig. 23, to cover the range of angle *a* from 70 to 140 deg.

Width of Crest of Beam

If an observer walks across the width of a beam at some distance from a searchlight, he will observe that as he first enters the beam only the center of the mirror will appear luminous. As he comes nearer to the axis, the luminous area will grow until at the point where he enters the inverse-square region the entire mirror will appear luminous, and it will remain luminous until the opposite edge of the region is reached.

A plot of the apparent beam candles along this line of traverse will show a flat crested curve, somewhat resembling a sine curve with the top flattened. The width of the flattened part is proportional to the distance from the beginning of the inverse-square region, as in Fig. 22, but the curve will necessarily be plotted in degrees measured about the searchlight. It is evident that here is a discrepancy that may be diminished but never wholly overcome. The problem is to find what the practical aspect of this difference is, for while at a great distance the angular width would be sensibly equal for either the searchlight or the L_0 point as a center, the conditions of test and service place a limit on the range of the traverse.

Let the radius of the light source subtend an angle e from the edge of the mirror, then the beam from this point, which fixes the boundaries of the inverse-square region, has a divergence e either way from the axis, and we can write

$$L_0 = y \cot e \tag{51}$$

for the point where the inverse-square region has zero width.

At some greater distance L measured from the searchlight, the half width is

$$\frac{W}{2} = (L - L_0) \tan e \tag{52}$$

The apparent angular width here is e', giving

$$\tan e' = \frac{W}{2L} \tag{53}$$

and the error E caused by using e' in place of e is

$$E = \frac{e' - e}{e} = \frac{\frac{W}{2L} - \frac{W}{2(L - L_0)}}{\frac{W}{2(L - L_0)}}$$

$$E = \frac{L_0}{L} \tag{54}$$

where tan e and tan e' have been replaced by the angles e' and e. If e' is to be correct to within 10 per cent then L must be 10 times L_0; while if L is to be correct to within 1 per cent then L must be 100 times L_0. This indicates extreme testing ranges; and the tests cannot well be replaced by computations for a complete geometrical analysis is beset with many difficulties, chiefly because solid geometry and solutions by trial and error are necessary. A better and far simpler method will be given when the graphical solution for beam intensity is outlined.

Figs. 25, 26 and 27 show how the active area grows as the beam is entered from the side. The irregular form of the active area, although due in part to optical errors in the mirror, is a clear warning of the difficulty of a strict analysis for intensity in the sides of the beam.

Figs. 25, 26 and 27. Eighteen-inch Searchlight Mirror Images of Spiral Filament seen from a radius of 145 ft. at points 1 deg. 30 min., 0 deg. 45 min., and 0 deg. 0 min. respectively from the axis

(To be continued)

Full and Semi-automatic *Versus* Manually Operated Substations for Electric Railways

By Cassius M. Davis

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The author compares the relative merits of automatic, semi-automatic and manually operated substations. He first deals with interurban systems and then with city systems. In each case he considers the pros and cons for these systems of substation operation in considerable detail. This paper was read before the midwinter convention of the Central Electric Railway Association held at Louisville, Ky., on January 18, 1923. Editor.

Introduction

Automatic and semi-automatic substations were introduced primarily as a means of conserving labor. On interurban roads in particular the expense for labor is a large part of the total annual cost of supplying power to the trolley; therefore, anything which will lower this expense is worthy of consideration. That automatic substations have lived up to expectations in this respect cannot be denied and they have given a good account of themselves from an operating point of view.

After the first few equipments were tried out and their success seemed assured, several engineers started a careful study of their application to specific railways. It was soon shown the automatic and the semi-automatic substation offered a new economic means of effecting many improvements in operation in addition to the reduction in labor expense. Schedule speeds might be increased at a minimum expense, improvement in distribution and conversion economics made possible, while additional capacity for new load centers could be provided in a most economical manner, etc.

The many advantages possessed by automatic control become evident when certain fundamental engineering and economic principles are borne in mind. It will be the purpose of this paper to present briefly some of these principles, none of which are new, and to suggest their application in making a comparison between manual and automatic control.

It will be appreciated at the outset that there are several important differences between interurban and city systems. These differences come about primarily because the interurban railway represents essentially a lineally loaded system while the load on a city system is distributed over an extensive area. A single substation on an interurban system usually feeds only a given length of a single route while in the city one substation may feed portions of several routes and the length of feed is indefinite.

It will be well, therefore, to consider the two classes of systems separately, and since the interurban railway represents the simplest problem, this will be considered first.

Interurban Systems

On the average interurban railway the cost of the labor conserved by the use of automatic control is considerably in excess of the fixed charges on the additional equipment. This applies to both single and two unit substations, although, of course, to a lesser extent in the case of two units. Automatic control for a single unit substation yields a gross return of from 25 to 40 per cent on the investment.

Since the total annual substation operating expense is less for the automatic than for the manual substation, it is possible to strike a new balance between the substation spacing and the amount of feeder conductor. It may be found that a substantial saving in feeder copper can be realized.

This same principle applies in another form to the case where it is necessary to improve the voltage conditions on the trolley. A balance can be struck between the fixed charges on the necessary additional copper and the annual operating expenses of additional automatic substations to accomplish the same result. The result is frequently greatly in favor of the substations. For example, as against $650,000 in feeders the desired end is obtained on the North Shore Line by the use of automatic substations for about one-quarter this amount. The fixed charges on the substations would come to only about one-third those on the feeder copper.

If estimates indicate automatic substations are more economical than additional feeder copper to accomplish a desired result, then, as an incidental advantage, the track drop will be reduced and the distribution efficiency increased. Due to the fact that the negative return circuit is usually of considerably greater conductivity than the positive circuit, it is frequently very expensive to control the track drop. Frequent spacing of automatic substations, therefore, provides a means of breaking up this drop in a very effective manner. The bearing of this principle upon the mitigation of electrolysis is obvious, although its application is of greater importance in city service than on an interurban line.

There are two features in the control itself which must be borne in mind when considering the economics of substation location. The first of these is the load limiting resistor. It performs a three-fold function of replacing the ordinary overload circuit breaker, limiting the output of the substation, and transferring part of the overload to adjacent substations. All these functions are of particular importance in interurban service. An overzealous motorman accelerating a heavy train in the vicinity of an automatic substation does not trip the substation breakers and deprive the train of all power for several seconds, but instead a block of resistance is cut in circuit and for the time being reduced voltage is obtained and acceleration continues at a lower rate. Again the bunching of trains and their simultaneous acceleration offer no difficulties in the operation of an automatic substation. If the load on the substation becomes excessive, one or more blocks of the resistor are cut in and protect the machine. At the same time reduced voltage is available at all the trains enabling them to get under way. When such a condition occurs the adjacent substations assist in supplying power. The amount of this supply, of course, depends upon the voltage at the load and the resistance between substations. The functioning of the equipment as just outlined actually makes each substation a reserve for its neighbors and thus becomes an important factor in selecting the size of substation equipment. There are some 500 kw. units now in operation which, if under manual control, would be entirely inadequate and would have to be replaced by 750 or 1000 kw. units.

The second feature of the control itself which has a direct bearing upon the economics of operation is that which permits the converting equipment to shut down during periods of light or no load. It is possible to adjust the control so that a given substation is in operation only when a substantial load can be carried. The load factor and conversion efficiency are not only improved but the running-light losses, which amount to from 3 to 7 per cent of the machine capacity, are eliminated.

The elimination of labor has a decided effect upon the design of substation buildings. A much cheaper, and in some cases, a smaller building can be provided. Windows can be practically done away with, space and conveniences for operators may be absent, and no provision for heating is necessary. In fact the building may be of the simplest and most compact type.

The above statements cover the chief principles encountered in the consideration of automatic versus manual substations. There are various advantages arising from the use of automatic control which may be of more or less value to the operating company depending upon circumstances. It is not proposed to go into these here, however, beyond mentioning that certain modifications of control are possible and that certain portions of the equipment are available to accomplish certain results. For example, the load limiting resistors or reclosing control for feeders may be applied to existing manual substations to advantage. Or, instead of designing a substation to start and stop upon load demand, it may be arranged for time switch or remote control. In other words semi-automatic control may be employed to advantage in some cases although frequently all the possible economics available are not realized.

City Systems

The conservation of labor by the use of automatic substation control applies in city systems as well as on the interurban line and, in general, similar principles of application are evident. There are certain factors and basic assumptions, however, which require careful consideration in order that a fair comparison with manual control may be made on a metropolitan property.

The problem frequently takes the form of a comparison of a few manual substations versus many automatics. If this is the case the city may be divided into load zones and the comparison simplified such that, in effect, one manual may be compared to three or four automatic substations.

The first basic assumption to be made is that the substation apparatus and d-c. distribution plant per se are equally reliable in operation and therefore no greater reserve equipment is required for one scheme than the other. It may be that one scheme offers certain advantages over the other during times of emergency; but if such be the case they are intangible advantages which must be capitalized according to the best judgment of the operating department.

Since the comparison between the two schemes is an economic one, the next basic assumption is that the same average trolley voltage must be used throughout the discussion. This is important since a change in trolley voltage not only affects the speed of the cars, and with it the platform expense, but also the distribution losses and total power output of the substations. Furthermore, the trolley voltage assumed affects the amount of feeder conductor required and therefore the capital expense. If it is impossible to assign the same trolley voltage to both schemes then the differences resulting must be estimated and the equivalent capital expense debited to the proper scheme.

Another basic assumption is an equality in both schemes of track and negative return drop. Track drop is difficult to predetermine and also difficult to control, consequently, in practice, it is impossible to adhere to this assumption. In lieu thereof, the advantages and disadvantages of each scheme in this respect must be estimated and a value assigned.

A final basic assumption is that the load on the system and the area covered must be alike for both schemes. When dealing with loads expressed in amperes this assumption is intimately associated with the assumption stated above regarding trolley voltage.

The underlying principles in the application of a multiplicity of small substations is that, compared to a single large station, the amount of positive copper required is theoretically in an inverse ratio to the number of substations. This is based on the assumptions previously mentioned.

The limit toward which this principle leads is that number of substations which permits the elimination of all feeder conductor and the entire load is carried by the trolley.

In the practical application of this principle it is impossible to realize the theoretical saving in positive conductor due to the many local conditions such as non-uniformity of load distribution, methods of sectionalizing the trolley, the use of negative feeders to avoid unnecessary electrolysis hazards, proximity of other points of power supply, insurance against interruption of service, local city ordinances, building restrictions, etc. This principle serves then primarily as a criterion by which to judge how well an proposed scheme is laid out.

The next principle is that the number of substations in operation can be made proportional to the load, maintaining the conversion efficiency at a maximum.

The d-c. distribution efficiency remains the same regardless of the number of substations. This is due again to the assumption that the same average trolley potential is maintained and that the load is evenly distributed. Actually the distribution efficiency will be slightly higher since feeders will parallel the trolley wire even where calculation would indicate the average voltage would be maintained without supporting feeders.

The a-c. distribution system, if laid out for uniform voltage drop, would have the same efficiency regardless of the number of substations. This cannot usually be accomplished and a slightly lower efficiency results in practice which offsets the gain in efficiency mentioned in the preceding paragraph.

The peak load on a city system does not appear simultaneously at all parts of the system but only at a few relatively widely separated localities. It then gradually shifts to other parts of the city. Hence the greater the number of sources of power the shorter will be the feeds to the load peaks and consequently the more efficient will be the d-c. distribution.

Another principle is that the number of substations selected and their locations must be such as to produce the most economical operating results. An aggregate of several small substations cost more than a single substation of the same total capacity. The difference, however, is offset by the smaller amount of positive and negative conductor required in the former scheme. By means of automatic control the small stations can be operated with a minimum of labor, they can also be operated with a minimum of light load losses.

A final principle concerns reserve capacity. In a single large manual substation at least one machine, equal in capacity to the largest, must be held in reserve. Thus there is always one idle unit upon which fixed charges must be carried. With a multiplicity of small substations, however, each acts as a reserve for all those surrounding it. Consequently, the loss of a unit in a small substation is of little consequence since its load would be picked up by several other substations. From this it follows that the reserve in the case of several small substations is included in the normal capacity and is always an active reserve earning a return on the investment.

The comparison between manual and automatic control for metropolitan systems is necessarily close, the more so the denser the traffic. There are also more intangible advantages and disadvantages than are encountered in interurban systems; local conditions and restrictions also have, at times, almost a determining influence. All these render it difficult to make specific statements which are of value in connection with city substations as a class. It is hoped, however, that the general discussion given above will serve to stimulate thought and action on the application of this most recent agent of substation economy.

Atmospheric Nitrogen Fixation

PART II

By Eric A. Lof

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In Part I, published in our March issue, the author dealt with many of the general aspects of atmospheric nitrogen fixation and concluded with a description of the arc process. In this issue he deals with the cyanamid, cyanide, nitride, Haber and Claude processes.—Editor.

THE CYANAMID PROCESS

The cyanamid process is based on the ability of calcium carbide to absorb free nitrogen forming a nitrogen compound known as calcium cyanamid or more generally under its commercial name of simply cyanamid.

The calcium carbide is produced in huge electric electrode furnaces in capacities up to as high as 20,000 electrical horsepower each. The furnaces are kept filled with a mixture of calcined lime and coke, and the electric current passing through the mixture between the electrodes melts the lime to a liquid which then combines with the coke in the interior of the furnace, forming calcium carbide, the reaction being as follows:

$$Ca\,O+3\,C=Ca\,C_2+CO$$

The furnace is tapped every fifteen to twenty minutes into chill cars, the carbide when leaving the furnace having a temperature of about 4000 deg. Fahr.

A supply of pure nitrogen free from oxygen is essential with the cyanamid process. It is obtained by liquefying air under intense cooling and high pressure. Such liquid air machines work under pressures of 500 pounds per square inch, and with cooling by expansion the air is reduced to liquid form at 380 deg. Fahr. below zero. By then allowing this liquid air to warm up slightly, pure nitrogen gas boils off first, leaving the oxygen behind in the liquid. The nitrogen is then pumped to the fixation building.

After the carbide has cooled in the cars, it is crushed and powdered. It is then placed in cylindrical perforated paper cylinders in the fixation ovens. These are then heated electrically by passing an electric current through a carbon rod which extends through the center of the charge. When the temperature reaches about 2000 deg. Fahr., the nitrogen from the liquid air plant is admitted. The carbide absorbs the nitrogen, forming a new chemical compound, calcium cyanamid. The nitrogen fixation is represented by the equation:

$$Ca\,C_2+N_2=Ca\,CN_2+C$$

When the absorption is complete, the charge is removed from the oven, allowed to cool, and crushed to a powder. It is then hydrated or treated with a small quantity of water to remove the last traces of carbide and to slake any free lime present. Sometimes it is also treated with a small amount of oil to prevent dusting. It is then known by the trade name "Cyanamid," and has a nitrogen content of about 19 to 21 per cent.

Cyanamid is extensively used as an ingredient in mixed fertilizers, but during the past few years it has also been used to a great extent as a source of nitrogen for making other products such as ammonia, various ammonium compounds, nitric acid,· etc. The next step for either of these is the production of ammonia, which is obtained by heating cyanamid with steam under pressure in so-called autoclaves, when the nitrogen is given off as ammonia gas. This gas may be absorbed in water, producing aqua ammonia, which is used in large quantities for refrigeration and for many general chemical purposes. It may also be used for producing anhydrous ammonia by drying the gas and compressing it. Such ammonia is also used extensively for refrigeration purposes.

By absorbing the ammonia gas in sulphuric acid, sulphate of ammonia is formed, which is separated out by crystallization in the same manner as previously explained under the by-product coke oven process.

Similarly, by absorbing the ammonia gas in nitric acid, ammonium nitrate is formed, which is used to a large extent in high explosives. The nitric acid required for this product may also be obtained from the ammonia gas by oxidation of the ammonia in the presence of a heated catalyst, usually platinum, according to the following reaction:

$$4\,NH_3+5\,O_2=4\,NO+6\,H_2O$$

A mixture of about 10 volumes of ammonia gas and 90 volumes of air is passed over a spongy platinum screen of very fine mesh, heated electrically to a dull red heat, the temperature with the gas passing over it being about 1000 deg. Fahr. The gas velocity must be very high so as to cut down the time of contact between the gas and the catalyzer to about 1/100 of a second. The efficiency of conversion is quite high, about 90 per cent, and the resulting strength of the nitric oxide gas about 8 to 9 per cent, as compared to 2 per cent with the arc process.

The nitric oxide after leaving the catalytic burners is thereafter treated in the same manner as with the arc process; that is, it is passed through oxidation tanks, steam boilers and aluminum coolers and finally to the absorption towers. The absorption system is, however, much smaller than with the arc process, due to the much higher concentration of the nitric oxide and for the same reason the weak acid will have a strength of about 45 per cent instead of 30 per cent as with the arc process.

Fig. 7. Airplane View of the United States Nitrate Plant No. 2 at Muscle Shoals, Alabama

There are a large number of cyanamid plants throughout the world, their total annual productive capacity being possibly in the neighborhood of 1,250,000 tons of cyanamid, equivalent to a fixed nitrogen content of about 250,000 tons. Based on a power requirement corresponding to 2½ tons of cyanamid per

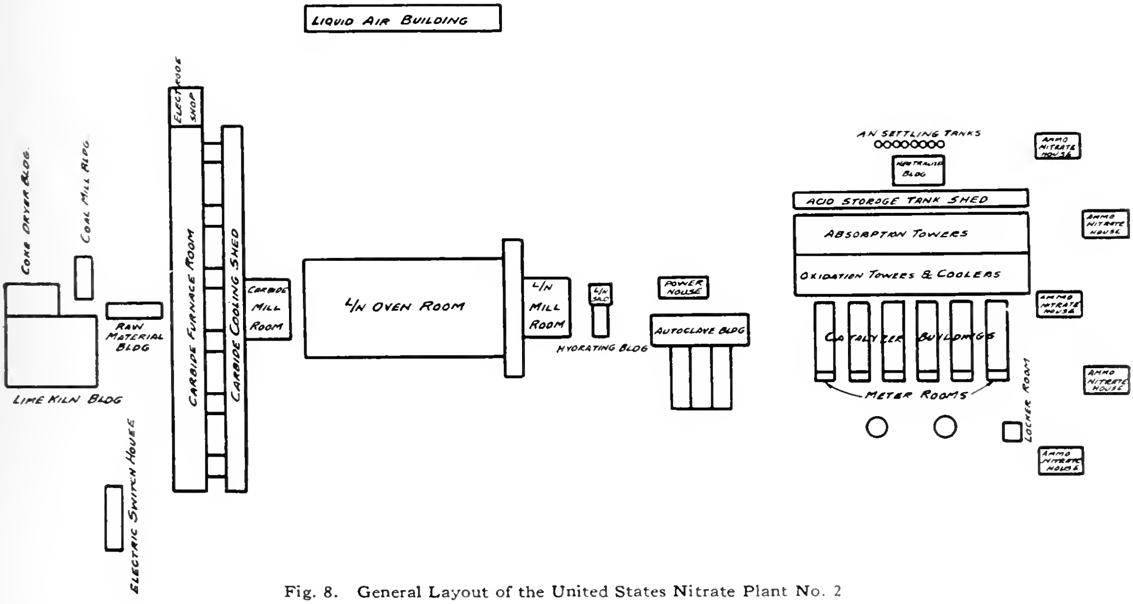

Fig. 8. General Layout of the United States Nitrate Plant No. 2

electrical horse power year, or 2 horsepower years per ton nitrogen fixed as cyanamid, the power for this total output would be no less than one-half million horsepower years. As compared to the arc process the relative power consumption for the cyanamid process per ton fixed nitrogen is only one-sixth of what it is for the arc process.

The large government nitrate plant at Muscle Shoals, Ala., built according to the cyanamid process, is generally known under the name of United States Nitrate Plant No. 2, and was built for the Government in 1918 for the production of ammonium nitrate for military explosives, the productive capacity of the plant being 110,000 tons of this product per year. The plant was constructed by the Air Nitrates Corporation, a subsidiary to the American Cyanamid Company, whose process was followed. Incidentally, it might be stated that the plant was completed shortly after the armistice, and one unit (one-fifth the plant capacity) was thereafter put through a two weeks' complete test operation, which thoroughly demonstrated the technical success of the undertaking.

THE CYANIDE PROCESS

The fixation of nitrogen in the form of alkali cyanides has not reached any commercial importance, although considerable research work has been done along these lines and a few small plants actually constructed. One of these plants was built by the Government during the war at Saltville, Va. Its capacity was very small, only 10 tons of sodium cyanide per day, the plans being to convert this cyanide into the highly poisonous gas, hydrocyanic acid, for the war.

The process of fixation on which the Saltville plant was based is known as the Bucher process, the reaction involved therein being as follows:

$$Na_2\,CO_3+4\,C+N_2=2\,Na\,CN+3\,CO$$

The raw materials are soda-ash and coke in pulverized form to which iron, also in powdered form, is added, its action, however, being purely catalytic. This material is formed into briquettes, thoroughly dried, and then heated in retorts at a temperature around 1500 deg. Fahr., while nitrogen is passed through the mass. As high as 18 per cent of nitrogen has thus been fixed in the form of cyanide.

When sodium cyanide is once formed it can be converted into ammonia like cyanamid, and the process has the advantage that in this conversion the soda-ash can be recovered and used over again. The iron can also be repeatedly used.

A cyanide process has also quite recently been invented in Sweden. A moderate size plant was built and operated for some time, but is now closed down, and the opinions of specialists seem to be divided as to the commercial success of the process.

The process is of the continuously operated type, the materials being kept in continuous circulation in such a manner that the nitrified portions are decomposed into ammonia leaving a solid residue which is returned to the nitrification building with the addition of some fresh material.

The raw material, consisting of anthracite, sodium carbonate and iron sponge, is formed into small balls in which shape they are fed into the furnaces. These are of the shaft type, the material resting on grates which are intermittently turned in order to facilitate discharging and to avoid baking. The furnaces are further of the electrode type operating on the resistance principle, the balls themselves conducting the electric current from one electrode to the other and become in this way heated to the temperature required for the reaction, which is around 1700 deg. Fahr. The nitrogen under pressure is admitted directly at the bottom of the furnace, and the gases are given off at the top. They contain principally hydrogen and carbon oxide, which is afterward used as fuel gas for the nitrogen ovens and for drying purposes, etc. The bottom of the furnace is connected to an airtight conveying system for transporting the cyanide to the ammonium-sulphate building.

A large surplus quantity of nitrogen is needed for the fixation, and a method has been worked out for its production at a very low cost. The process is chemical, the oxygen of the air being bound by an alkali iron to Fe_2O_3, setting the nitrogen free. This ferric oxide is then reduced by the above-mentioned waste gas from the furnaces and the iron used over again. In practice, air is not used in the manufacture of the nitrogen, but the waste gases from the sulphuric acid factory, as these gases contain only a few per cent of oxygen, thus materially reducing the energy required for binding the oxygen.

The cyanide from the furnaces is, as mentioned, conveyed to the ammonia department where ammonium sulphate is produced in the same manner as for cyanamid, with the exception that the sludge left in the autoclaves after proper treatment is used again as raw material for the furnace charge.

The power consumption with this process is claimed to be about 1½ horsepower years per ton nitrogen fixed as cyanide.

Sodium cyanide is also made by fusing cyanamid with ordinary salt in an electric furnace. This product is extensively used for case-hardening of steel, for the separation of gold from its ore and for the manufacture of hydrocyanic acid for fumigation of fruit trees. Large quantities of such cyanide is manufactured by the American Cyanamid Company at their Niagara Falls plant.

THE NITRIDE PROCESS

The fundamental principle underlying this process is the combination of nitrogen with metals, such as aluminum, titanium, lithium, etc., to form nitrides from which ammonia can readily be obtained by decomposition.

The best-developed process of this type is the so-called Serpek process for making aluminum nitride from bauxite (aluminum oxide), coke and nitrogen according to the reaction:

$$Al_2O_3+3\,C+N_2=2\,AlN+3\,CO$$

Bauxite mixed with carbon is fed into the upper end of an inclined revolving kiln, the necessary heat for heating the mixture to the required reaction temperature of around 3200 deg. Fahr. being supplied by electric current. Producer gas, containing about 30 per cent CO and 70 per cent N_2 enters the lower end of the kiln and passes through the same in a direction opposite to that of the descending charge, and in the electrically heated zone, the nitrogen reacts with the alumina-carbon mixture and forms aluminum nitride, containing about 26 per cent of fixed nitrogen. The carbon monoxide also formed by the reaction is being used for preheating the charge before it enters the kiln.

Ammonia is then formed by treating the aluminum nitride in autoclaves, this reaction being as follows:

$$AlN+3\,H_2O=Al\,(OH)_3+NH_3$$

In addition to the ammonia, a very pure alumina is obtained which can be used for metallic aluminum production. The power required is approximately the same as for the cyanamid process, that is about 2 horsepower years per ton nitrogen fixed as nitride.

Like the cyanide process, the nitride process has not been of any great importance in connection with the nitrogen fixation problem. A few moderate-size plants have been built in this country and abroad, but it can hardly be said that the process has as yet been fully developed.

THE HABER PROCESS

This process, named after its inventor, Prof. Fritz Haber of Germany, was introduced there shortly before the war, and was one of the most important factors of insuring Germany of an ample supply of nitrogen during the war, and this with a much lower power requirement than any of the synthetic processes previously described. Germany now possesses two enormous Haber plants at Oppau and at Merseburg. The former, where the terrible explosion occurred in 1921 has a productive capacity equivalent to 100,000 tons of fixed nitrogen per year and the Merseburg plant twice this, thus a total of 300,000 tons nitrogen per year. Two plants, but of comparatively small capacity, have been built in this country. One of these was built by the Government at Sheffield, Ala., during the war, but has never been in actual operation, except what might be termed experimental operation. The other plant was built in 1921 by the Semet-Solvay Company at Syracuse, N. Y. The process of these two plants is a modification of the German Haber process developed by the General Chemical Company, the operating pressure being only about one-half that which is used in Germany.

The Haber process consists briefly in passing a mixture of one volume of nitrogen and three volumes of hydrogen (the constituents of ammonia) at a pressure of from 100 to 200 atmospheres over a suitable catalyzer at a temperature of some 900-1000 deg. Fahr. The nitrogen and hydrogen will then combine and form ammonia according to the reaction:

$$N_2+3\,H_2=2\,NH_3$$

A single passage of the gas mixture through the catalytic chamber causes a conversion of about 6 to 8 per cent (by volume) of the nitrogen-hydrogen mixture to ammonia, this being recovered either by refrigeration and condensation to anhydrous ammonia or by absorption in water to aqua ammonia, which can again be converted into gaseous form by distillation. The unconverted nitrogen and hydrogen mixture, still under the above pressure, is replenished with a fresh gas mixture corresponding to the separated ammonia, after which it is reheated and returned to the catalytic chamber, thus repeating the cycle.

Besides the mechanical difficulties due to the high pressures at which the process is operated, the solution of the very complicated chemical problems which are involved has required an enormous amount of experimental and research work. It is absolutely essential

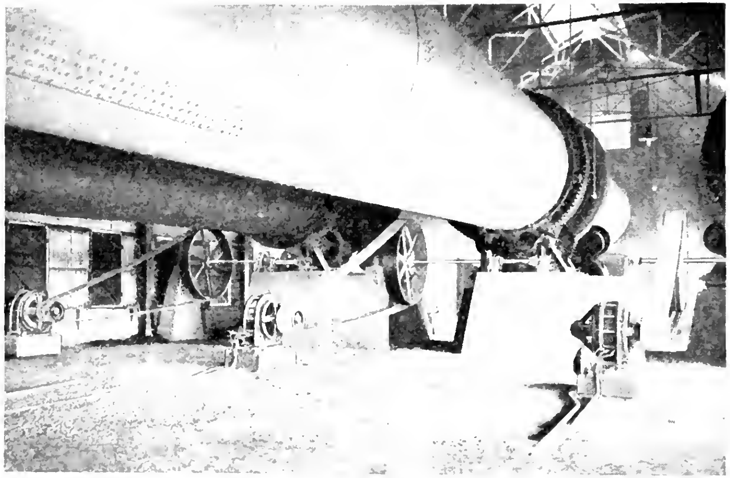

Fig. 9. Motor-driven Rotary Lime Kilns at the United States Nitrate Plant No. 2

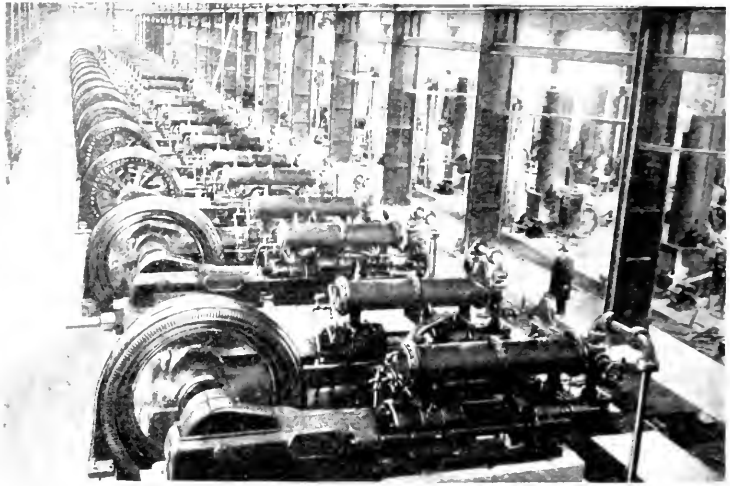

Fig. 10. Synchronous Motor-driven Air Compressors in the Liquid-air Building at the United States Nitrate Plant No. 2

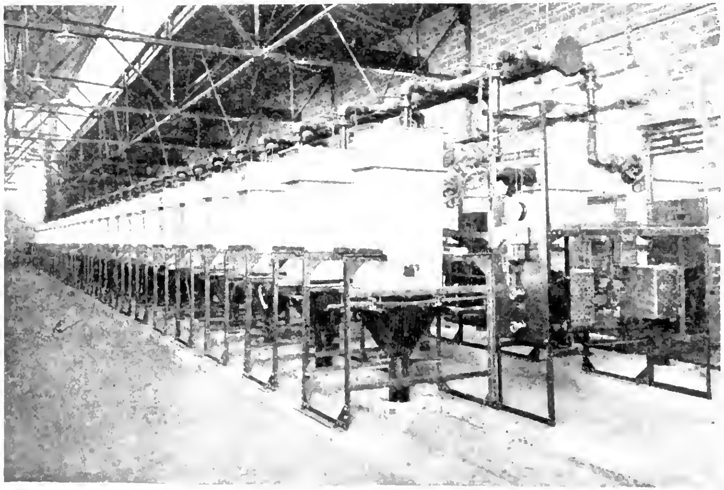

Fig. 11. Catalytic Platinum Burners in the Ammonia Oxidation Building at the United States Nitrate Plant No. 2

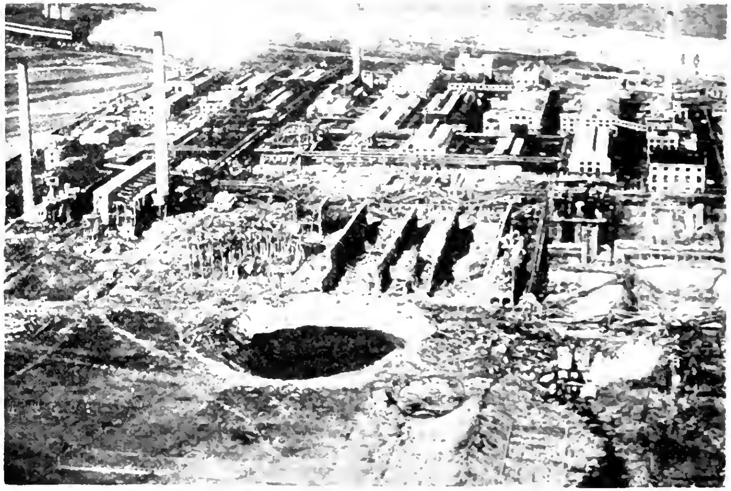

Fig. 12. Airplane View of the Haber Synthetic Ammonia Plant at Oppau, Germany, after the Explosion in 1921

that the two gases, nitrogen and hydrogen be in a very pure state, as even minute quantities of impurities such as carbon monoxide will be poisonous to the catalytic material and the two gases will refuse to combine or do so at a very reduced rate. It is this preparation and purification of the nitrogen and hydrogen and especially the latter, which comprises the chief items of cost in the Haber process.

The problem of providing a durable and suitable catalyst has also been a difficult one. The reaction when the two gases combine to form ammonia can only take place in the presence of what is known as "catalytic" metals. A catalyst, therefore, is simply a substance which promotes the union of two elements with each other, without itself entering into the combination.

Water is naturally the source from which hydrogen is produced, either chemically or by electrolysis. In the former method, water gas is first generated in a gas producer in the ordinary way by passing steam over incandescent coke. This gas consists of one-half volume of hydrogen, the other one-half being chiefly carbon monoxide, as seen from the following equation:

$$C+H_2O=CO+H_2$$

In order to remove this carbon monoxide it is found desirable to convert it into carbon dioxide which can readily be separated by water scrubbing at a pressure of around 25-30 atmospheres. The equation for the reaction is:

$$CO+H_2+H_2O=CO_2+2\,H_2$$

and it is caused by letting an additional quantity of steam react on the gas in a special converter, also with the help of a suitable catalyst. The advantage of this method is obviously that twice the amount of hydrogen is obtained with the same gas producer. The pressure is obtained with no extra cost because the gas must sooner or later, anyhow, be compressed to a still higher pressure as previously stated.

Pure hydrogen can be produced by electrolysis of water but in order that this method shall be commercially feasible, cheap power is essential.

The process used at the Government Synthetic Ammonia Plant at Sheffield, Ala., was a modified water-gas process by which the hydrogen and the nitrogen is produced simultaneously. It is thus possible to directly provide a mixture in the right proportions, if instead of steam, a mixture of air and steam is passed over the incandescent coke in the gas producer; or in other words, if instead of water gas, a semi-water gas is produced consisting of five volumes of hydrogen, seven volumes of carbon monoxide, and four volumes of nitrogen. After the seven volumes of carbon monoxide have been converted into seven volumes of carbon dioxide and hydrogen, in the manner previously explained, and the gas freed from carbon dioxide, then it contains evidently twelve volumes of hydrogen and four volumes of nitrogen or hydrogen and nitrogen in the correct proportions, 3:1, for ammonia. The following equations will possibly make this clearer:

$$\overbrace{5\,H_2O}^{\text{Steam}}+7\,C+\overbrace{4\,N_2+O_2}^{\text{Air}}=5\,H_2+7\,CO+4\,N_2$$
$$7\,CO+7\,H_2O=7\,CO_2+7\,H_2$$

Adding the hydrogen and nitrogen values from the right-hand side of these two equations we thus get

$$5\,H_2+7\,H_2+4\,N_2=12\,H_2+4\,N_2=8\,NH_3$$

In the German Haber plants the hydrogen is produced by the water-gas method and the nitrogen by separate lean-gas producers. Some free nitrogen is also required around the plant for various purposes, especially for adjusting the hydrogen-nitrogen mixture before it enters the synthetic reaction chamber. This nitrogen is made by the liquid-air distillation method. This process could, of course, be used for manufacturing all the nitrogen required but it is a question whether it will be economical unless cheap power can be obtained for driving the refrigerating compressors.

The gases after leaving the respective producers are first thoroughly washed by water separately. The main purification, however, is done after the gases have been mixed, and consists in first washing the gas with water under a pressure of around 25 atmospheres for removing the bulk of the carbon dioxide. After this the gas is brought up to the final process pressure of 100-200 atmospheres and washed with chemical solutions for removing the final traces of CO and CO_2 after which it is passed through the catalytic ammonia reaction chamber. In the Sheffield Plant the gas mixture is brought up to its final pressure of 100 atmospheres in one step and the water scrubbing for removing the carbon dioxide is done at this pressure.

The gases which have been converted to ammonia in the catalytic chamber are removed by means of refrigeration or water absorption and the uncombined gases returned to the system to be passed through the catalyzer chamber again until finally combined. The ammonia may be sold as anhydrous or aqua or absorbed in sulphuric acid or phosphoric acid to produce ammonium sulphate or ammonium phosphate the same as with the other processes, or a portion may be oxidized and absorbed to form nitric acid in which the remaining portion of the ammonia may be absorbed to form ammonium nitrate.

In producing hydrogen for synthetic ammonia by the water-gas method, it has been shown how large quantities of carbon dioxide have to be eliminated in the purification. As in the Solvay soda process thousands of tons of carbon dioxide are used each year for which large quantities of limestone are burned, it follows at once that the two processes can advantageously be worked together.

The ammonia gas and the carbon dioxide is passed into a brine solution and the products obtained are sodium bicarbonate and ammonium chloride.

$$NaCl+H_2O+CO_2+NH_3=NaHCO_3+NH_4Cl$$

The sodium bicarbonate, $NaHCO_3$, is readily converted into soda ash, Na_2CO_3, by heating when it loses all its water and part of its carbon dioxide gas.

$$2\ NaHCO_3=Na_2CO_3+CO_2+H_2O$$

Soda ash or sodium carbonate is extensively used in the glass, soap, paper, textile and numerous other industries.

The ammonium chloride, NH_4Cl, after proper concentration and drying, is at once ready for the market. It is claimed, but not substantiated, that ammonium chloride, which is a more concentrated nitrogen product than the sulphate and meets the other requirements also, is equal to the sulphate in fertilizer properties, just as potassium chloride is as available for crops as potassium sulphate.

The power requirements for the Haber process are very low unless the hydrogen should be produced by electrolysis and the nitrogen by liquid-air distillation. The reason for this is, of course, the fact that electricity does not enter into any of the reactions but is chiefly used for motive power.

Where the nitrogen and hydrogen is provided by the gas producer method the power requirements will amount to about ½ horsepower years per ton nitrogen fixed as ammonia, while if electrolytic hydrogen and liquid-air nitrogen is produced the corresponding figure would be around 3½ horsepower years.

THE CLAUDE PROCESS

This process, the invention of M. Claude of France, is a modification of the Haber process. It is as yet more or less in the experimental stage, but seems to offer great possibilities. Claude thus works with a pressure of 900 atmospheres as compared to 200 with the Haber process. By means of this high pressure about 40 per cent ammonia conversion is obtained per catalyzer unit, and the endothermic reaction will raise the temperature of the catalyst to the required temperature of 900-1000 deg. Fahr. with only a slight preheating, which is readily provided by simply passing the gas through an outer passage in the catalytic chamber. By using three catalyzer units in series, 80 per cent of the gases are converted into ammonia and only 20 per cent needs to be recirculated. The ammonia is readily removed by simply cooling it in a coil submerged in water when practically all the ammonia will liquefy.

The hydrogen and nitrogen may be obtained in the same manner as with the Haber process previously described. It is claimed, however, that the hydrogen from producer gas can be very efficiently purified at this super pressure. The compressed gas is passed through ether at a low temperature when all the gases but the hydrogen are dissolved by the ether. The solvent with the gases in solution is drained off, and when expanding to atmospheric pressure the dissolved gases escape, leaving the solvent ready for re-use.

THE CASALE PROCESS

This is also a synthetic ammonia process which has been developed in Italy where it is said to be used in one or two plants. It operates at a pressure around 500 atmospheres, or somewhat higher than the Haber process, for which reason a higher ammonia conversion should be expected. It is also claimed that a very satisfactory catalyzer has been found which is less affected by impurities in the hydrogen and nitrogen gases.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted, which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Circuit Breakers—Testing

Arrangement for Testing and Adjusting Excess-Current Relays of Automatic High-Tension Circuit Breakers. Delenk, A. (In German.)
Siemens-Zeit., Dec., 1922; v. 2, pp. 666-668.
(Brief description of apparatus and methods.)

Condensers, Static

Static Condensers for Power-Factor Correction. Marbury, R. E.
Elec. Jour., Feb., 1923; v. 20, pp. 49-51.

Electric Cables

Apparent Dielectric Strength of Cables, Wiseman, Robert J.
A.I.E.E. Jour., Feb., 1923; v. 42, pp. 165-170.
(A discussion of two earlier papers by Middleton, Dawes and Davis, and by Simons on the same subject.)

Electric Conductors

Wind Shielding between Conductors of Telegraph and Telephone Lines. Howe, P. J.
A.I.E.E. Jour., Jan., 1923; v. 42, pp. 20-26.
(Results of an investigation of the effect of wind on telegraph and telephone lines, especially when they are ice-coated.)

Electric Control Systems

A-C. Locomotive Control. Dory, Dr. Ivan.
Elec. Rwy. Jour., Feb. 3, 1923; v. 61, pp. 199-200.
(Review of plans used for varying voltage in European single-phase locomotives.)

Electric Drive—Steel Mills

Improving Rolling Mill Practice. Stoltz, G. E.
Iron Age, Feb. 8, 1923; v. 111, pp. 411-414.
(Abstract of paper before the Association of Iron & Steel Electrical Engineers. Discusses use of d-c. for main roll drives.)

Electric Furnaces

Electrically Heated Industrial Furnaces. Trinks, W.
Forg. & Heat Treat., Dec., 1922; v. 8, pp. 538-542.
(Compares efficiency of electrically heated and combustion types. Shows designs of heating elements and furnace construction.)

Electric Lighting

Influence of Daylight Illumination Intensity on Electric Current Used for Lighting Purposes in the District of Columbia. Smirnoff, A.
Illum. Engng. Soc. Trans., Jan., 1923; v. 18, pp. 36-46.
(Tests of the outdoor "psychological darkness" which results in electric light being employed in the business district.)

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Unique Type of Drive for Electric Locomotives.
Rwy. Elec. Engr., Jan., 1923; v. 14, pp. 20-21.
(Illustrated description of the Brown Boveri "individual axle drive" locomotive used on the Swiss Federal Railways.)

Electric Motors, A-C.

Variable-Speed Alternating-current Motors without Commutators. Creedy, F.
Engng., Jan. 19, 1923; v. 115, pp. 87-91.
(Paper before the I.E.E. Serial. Same, abstract, in *Engineer*, January 12, 1923, pp. 49-50.)

Electric Motors, Synchronous

Synchronization of Synchronous Motors on Load. Fraenckel, A.
Brown Boveri Rev., Dec., 1922; v. 9, pp. 243-254.
(Describes the theory of BBC equipment for synchronization.)

Electric Transformers

New Type of Transformer. Designed to Conserve the Oil and Eliminate Explosions. Dann, Walter M.
Elec. Jour., Feb., 1923; v. 20, pp. 53-56.
(Description of the Westinghouse "Inertaire" transformer in which nitrogen occupies the space above the oil level.)

Electric Transmission Lines

Cost of Transmission Lines.
Elec. Wld., Feb. 3, 1923; v. 81, pp. 271-274.
(General and price data on a 78-mile system of the Turners Falls Power & Electric Company.)

Qualitative Analysis of Transmission Lines. Goodwin, Jr., H.
A.I.E.E. Jour., Jan., 1923; v. 42, pp. 48-57.
(Method of calculating transmission lines.)

Radiation from Transmission Lines. Manneback, Charles.
A.I.E.E. Jour., Feb., 1923; v. 42, pp. 95-105.
(Theoretical study.)

Structural Engineering Problems in Transmission-Line Construction. Martin, James S.
Engrs. Soc. of W. Pa. Proc., Nov., 1922; v. 38, pp. 309-420.
(Extensive paper on design of transmission lines.)

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Back-to-Back Tests of Continuous-current Machines. Smith, C. F.
Elec. Rev. (Lond.), Jan. 26, 1923; v. 92, pp. 124-126.
(Outlines methods of such tests, which are also called Hopkinson tests.

Hydroelectric Plants

Hydraulic Power Plant Practice in Northern Europe. Anderson, Clifford N.
Elec. Wld., Jan. 13, 1923; v. 81, pp. 91-96.

Inductive Interference

Electrostatic Interference in Weak-current Circuits Due to Ungrounded Three-phase Lines. Nather, Eugen. (In German.)
Elek. und Masch., Dec. 24, 1922; v. 40, pp. 601-604.
(Theoretical discussion.)

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Reliability and Cost of Catenary Insulators. Austin, Arthur O.
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(Abstract of paper before the N. Y. Electric Railway Association.)

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Design of Structural Supports for Turbo-Generators.
Power, Jan. 23, 1923; v. 57, pp. 154-155.

Using Shims Instead of Wedges for Leveling Bases of Steam Turbines. Barker, Sr., Edgar C.
Power, Jan. 9, 1923; v. 57, pp. 58-60.
(Practical methods of turbine erection.)

Oscillographs

Expansion of Oscillography by the Portable Instrument. Legg, J. W.
A.I.E.E. Jour., Feb., 1923; v. 42, pp. 106-111.
(Illustrated description of a portable oscillograph.)

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Direct Reading and Computing Attachment for Sphere Photometers. Willis, Ben. S.
Illum. Engng. Soc. Trans., Jan., 1923; v. 18, pp. 62-66.

Poles, Wooden

Design of Wooden Pole Transmission Line. Crawford, Perry O.
Elec. Wld., Jan. 20, 1923; v. 81, pp. 151-155.
(Results of tests of wood poles.)

Power-Factor

Power-Factor as It Affects the Consumer. Murphy, L. J.
Elec. Wld., Jan. 13, 1923; v. 81, pp. 97-100.

Railroads—Electrification

Twelve Years' Experience with Alternating-current Traction.
Rwy. Age, Feb. 10, 1923; v. 74, pp. 381-382.
(Abstract of paper by H. W. H. Richards before the Institution of Civil Engineers. It tells of results obtained with single-phase operation on an English line.)

What Railroads Are Doing with Electric Traction. Oehler, A. G.
Rwy. Age, Jan. 6, 1923; v. 74, pp. 45-48.
(Summary of recent operating experiences on American and on foreign lines.)

Resistors

Application of Control Resistors. James, H. D.
Elec. Jour., Feb., 1923; v. 20, pp. 57-62.

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Use of the Bleeder Turbine in Industrial Plants. Moore, J. L.
Power Pl. Engng., Jan. 15, 1923; v. 27, pp. 126-128.
(Short article showing how the bleeder turbines may be used to advantage.)

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Stresses in Electric-railway Motor Pinions. Heymans, Paul and Kimball, Jr., A. L.
Mech. Engng., Feb., 1923; v. 45, pp. 93-95, 137.
(Determination of their distribution by the photo-elastic method.)

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Automatic Substations Success in St. Paul. Reinbold, Robert.
Elec. Wld., Jan. 13, 1923; v. 81, pp. 87-90.
(Illustrated account of equipment and experiences of the St. Paul Gas Light Company.)

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Design of Radio Towers and Masts: Wind-Pressure Assumptions. Elwell, C. F.
Elec'n, Jan. 26, 1923; v. 90, pp. 88-89.
(Abstract of paper before the I.E.E.)

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GENERAL ELECTRIC REVIEW

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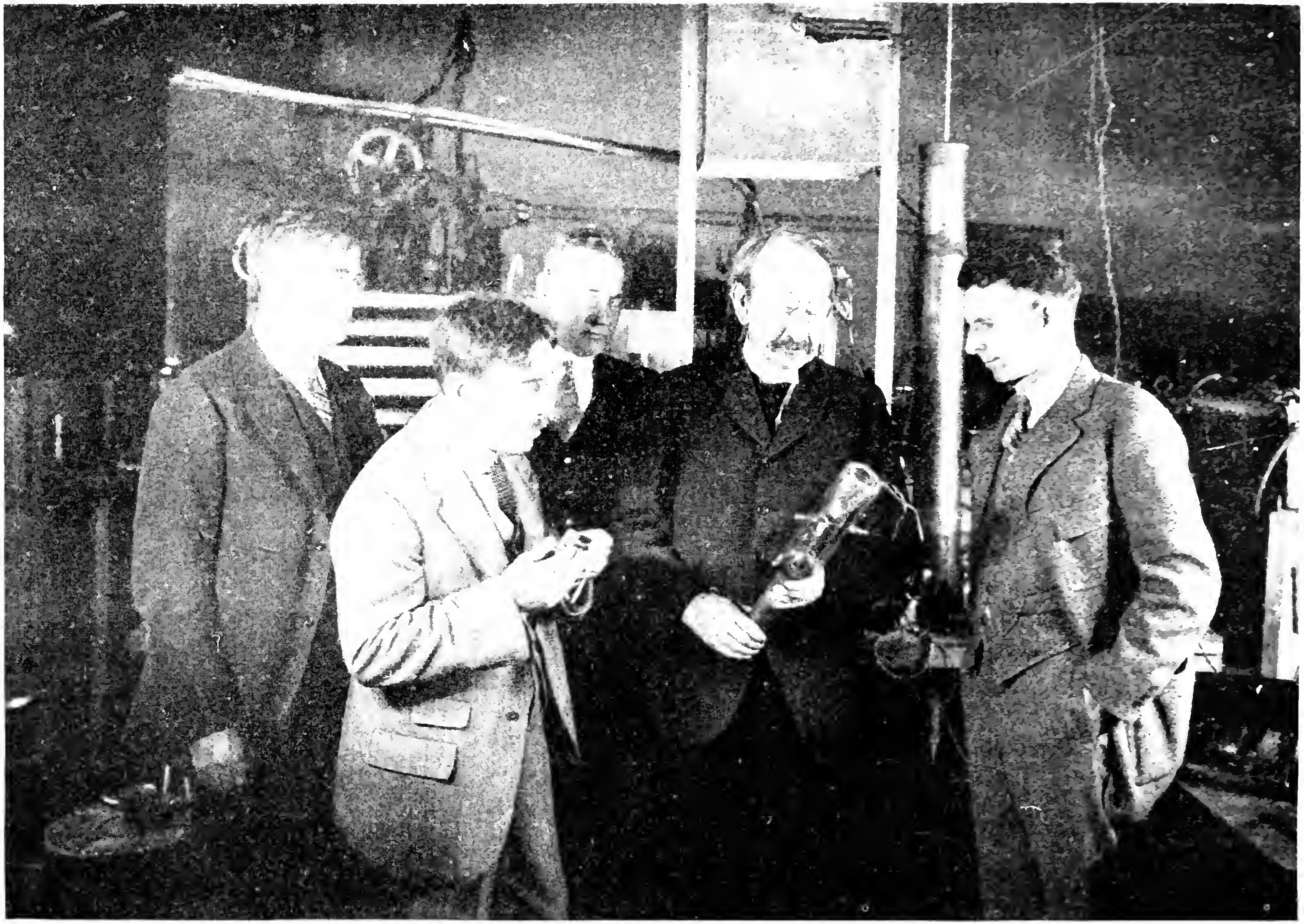

I. Langmuir R. B. Owens W. C. L. Eglin Sir Joseph Thomson W. D. Coolidge

Photograph taken in the Research Laboratory of the General Electric Company at Schenectady, N. Y., during Sir Joseph Thomson's Visit.
He is here seen examining a 20-kw. pliotron

GENERAL ELECTRIC
REVIEW

SIR JOSEPH JOHN THOMSON VISITS SCHENECTADY

The Research Laboratory and the Schenectady Works were honored on April 6th by the visit of Sir J. J. Thomson, for many years Cavendish Professor at Cambridge and now Master of historic Trinity College. We have entertained many distinguished visitors, including Lord Kelvin, Senator Marconi and Thomas A. Edison, but none more distinguished than "J. J.," as he is lovingly called by the workers in the great laboratory which he directed for so many years with such wonderful skill and inspiration.

Our visitor studied with interest and delight our Research Laboratory, which is largely devoted to work along lines which he himself laid down and largely guided by principles which he himself formulated. He also saw something of the great Schenectady Works, where twenty thousand men are engaged in work which has been made possible principally by his labors and those of his predecessors. Newton, Faraday, Maxwell and Thomson—these four names alone would bring glory enough to any nation. Newton was the founder of modern physics; Faraday's researches made possible the electrical transmission of energy and established the principles on which our own Edison and Elihu Thomson based their historic work; Clerk Maxwell's mathematical researches lie at the foundation of modern electrical knowledge; and J. J. Thomson has for more than a generation led in the development of the principles that these men established and in the broadening and deepening of that knowledge of basic truth which lies at the foundation of our own work and of all modern scientific and technical endeavor.

In particular, he has led us one step nearer to the ultimate—and a long step, a longer step than has been taken for a century, for it is more than a hundred years ago that his compatriot Dalton demonstrated that matter is made up of molecules and atoms. Thomson has told us how the atom itself is constituted, has shown us that each atom contains positive and negative electricity, the negatives existing as a number of little particles of electricity called electrons. Already this new knowledge has led to practical results of enormous value, and we are very proud of the part which our own Research Laboratory is taking in this work, a part which "J.J." graciously and generously acknowledged in a most inspiring address which he made on the evening of April 7th at a dinner given in his honor at the Mohawk Club.

It is only as the basic truths of nature are discovered that the application of those truths to the service of humanity becomes possible, and we of the General Electric Company, a concern whose prosperity and whose very existence are based on science and on the applications of science, are in a peculiarly favorable position to appreciate and to honor the man who has done what J. J. Thomson has done, and to recognize in him not only the greatest living physicist, but a worthy representative of the highest type of those devoted scientists and research workers who have discovered the scientific truths which have made our present prosperity possible.

Albert G. Davis.

Sir Joseph's visit to America is under the auspices of the Franklin Institute. He is to give several lectures during his visit, and we hope through the courtesy of the Franklin Institute to be able to tell our readers something about these lectures in future issues of the Review.

Electricity Masters Paper Making

By Robert H. Rogers

Power and Mining Engineering Department, General Electric Company

The art of paper making has progressed rapidly in recent years. Mr. Rogers describes the equipment of the first "all-electric" paper mill giving many facts and figures which will appeal to the reader.—Editor.

Canada has the honor of putting into production the first 100 per cent electric pulp and paper mill and it is already turning out "news" at the rate of three hundred tons per day. This means that the spruce and balsam from 75 acres of forest is spread to 1300 acres of newspaper, which is enough for an issue of 2,400,000 sixteen-page papers.

Every mechanical requirement in this complicated industry is met by electric motors ranging from ⅛ to 2400 h.p. in about 400 units. Ninety four per cent of the 34,000 h.p. connected load is developed by General Electric units.

The International Paper Company's newest mill is at Three Rivers where the St. Maurice river joins the St. Lawrence midway between Montreal and Quebec. Away upstream a timber tract the size of Massachusetts insures them many years supply of logs that can be floated to the mill. From Shawinigan Falls, in the same river, comes the hydro-electric energy that drives the mill.

Oil fuel for the boilers is delivered to the 140,000-barrel tanks during the summer by tankers from down the coast.

The St. Maurice also furnishes an ideal boiler feed and a clean colorless water that is so necessary to the production of a bright sheet of paper. Water enters into the processes in great quantities. The main pumping station at the river bank, Fig. 2, has a capacity of 55,800 gallons per minute or enough to supply a city of 700,000 inhabitants. Within the mill there are three great circulating systems which together with the makeup and interdepartmental flows aggregate the unbelievable pumping duty of 2500 tons per ton of paper produced.

The pumps all told have a capacity of 140,000 gallons per minute or 800,000 tons per day and every pump is a centrifugal direct connected to a General Electric motor.

Electric power is used at 2200 volts and 550 volts alternating current from the twin 24,000-kw. transmission lines, and at various direct-current voltages from the turbine generators whose exhaust steam is required for drying the paper. The balanced requirements of direct current for adjustable speed work and exhaust steam for drying makes a very fitting arrangement.

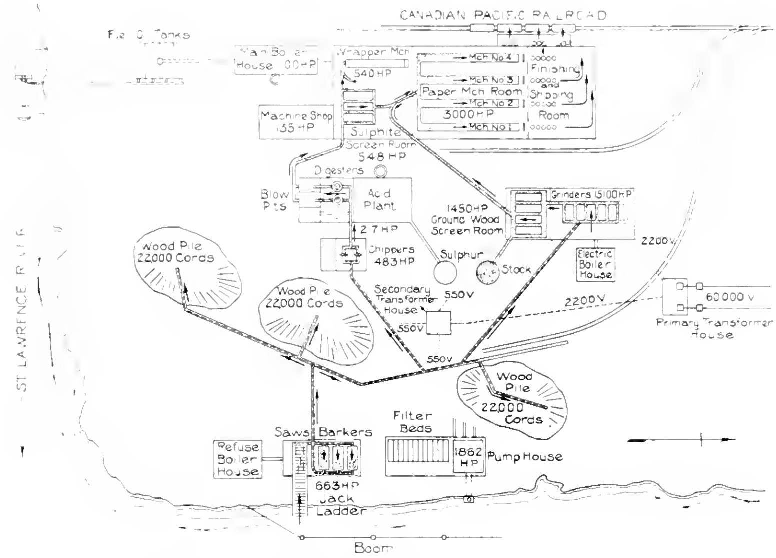

Fig. 1. Diagrammatic Plan of the Paper Mill of the St. Maurice Lumber Co., and of the Flow of Material from the Log Boom in the River to the Loaded Freight Cars. A cord and one-quarter of wood is converted into a ton of paper every five minutes

There are 522 employees including all supervision and, as the mill is operated by three "shifts," one is impressed more by the absence of employees than by their presence.

One ton of newspaper is represented by one and one-half of the familiar 6-foot rolls and will print eight thousand 16-page papers. As being manufactured in this mill, using all the figures over a period of one month, it represents:

(a) One and one eighth cords of wood.
(b) Three and one eighth barrels of fuel oil.
(c) Seven tons of steam.
(d) Fifteen man-hours of labor.
(e) 13,407 kw-hr. of hydro-electric energy.
(f) Five minutes for production.

Reference to Fig. 1, the diagrammatic plan of the mill, will show that the logs are withdrawn from the river, sawed, barked and the excess over the daily requirement for the mill is stored in huge piles by stackers during the summer months. The logs are reclaimed and passed through two independent processes, the sulphite or chemical process, and the ground-wood or mechanical process. Twenty-five per cent of the pulp as it goes to the paper machine has come from the sulphite process and the remainder is ground-wood pulp. The diagram shows the connected motor load in each department, the incoming transmission lines and transformer houses, the arrangement of fuel tanks and main boiler house and the railroad connections.

Fig. 2. General View in Pump and Filter House where there is a Connected Load of 1862 h.p. in Direct-connected Pumps Having a Combined Capacity of 55,800 gal. per min. or Enough to Supply a City of 700,000 People. The weight of all the rotating parts and any unbalanced water thrust in the vertical units is carried on the suspension thrust bearings at the tops of the motors. The pumps are below the low-water level and the control units in the gallery are above the high-water level of the St. Maurice River

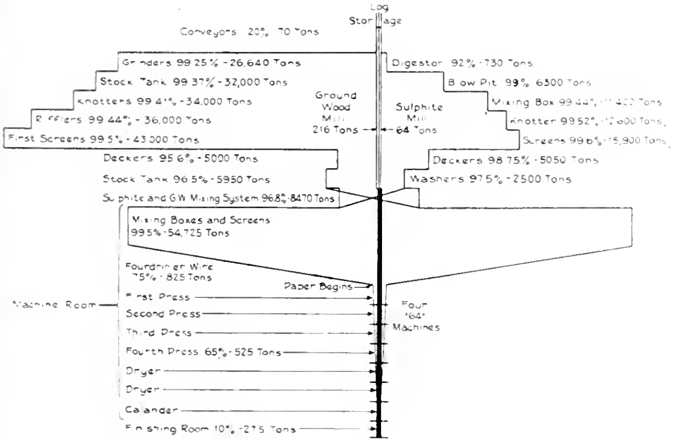

Fig. 3. Diagram Showing the Water Content on a 24-hour Basis Throughout the Various Processes. The ground-wood mill, the sulphite mill, and the machine room each have a circulating system, which, taken together with the make-up and interdepartmental pumping, makes the pumping duty 2500 tons per ton of paper produced. The combined capacity of all the pumps in the mill is 800,000 tons per day

The fall freezeup must find upwards of 60,000 cords of wood on hand to carry over the winter production. The cleaner logs are diverted to the sulphite system first going through the chippers which reduce them to small chips which are stored in an elevated chip bin. Bisulphite of lime, prepared in the plant by burning sulphur and passing the resulting gas through towers filled with limestone and dripping water, is stored close at hand for use in the digesters. The huge vertical digesters every eight hours take 20 cords of chips, about 25,000 gallons of bisulphite of lime and live steam up to 70 lb. pressure. About 250 boiler-horse-power-hours are required per ton of air dry pulp. The process of selective digestion lasts about eight hours and is for the specific purpose of digesting the ligneous and resinous binders without harming the cellulose ($C_9\ H_{10}\ O_5$) fibers that go into the paper. At the end of the "cook," the contents of the digester are blown into a covered concrete "blow pit" which has a perforated bottom through which the waste liquor drains off to the sewer. The steam and gas fumes pass off through high baffled towers called vomit stacks which are designed to prevent the escape of pulp. The pulp is now thoroughly washed in

Fig. 4. One of the Three Stackers and Less than Half of the 22,000-cord Pile that it had Accumulated During the Summer Season. Portable conveyors are reclaiming logs to the permanent conveyors which connect with the ground-wood and sulphite departments. Dynamite is sometimes required to dislodge the logs in winter

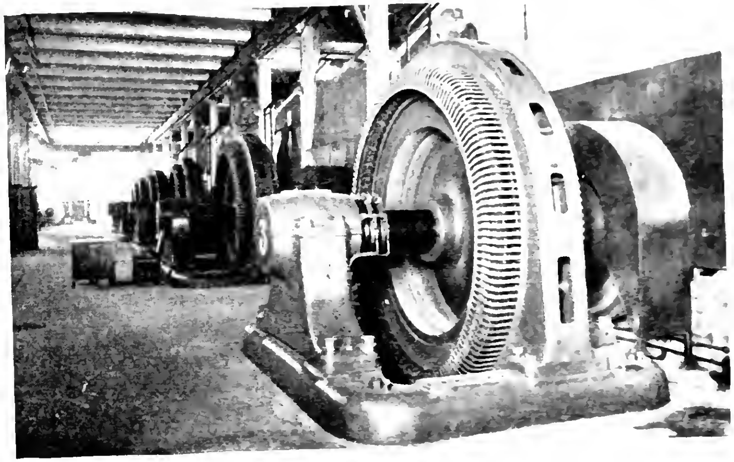

Fig. 5. This Lineup of Seven 2400-h.p., Synchronous Motors Drive the Grinders which Daily Reduce to Pulp 250 Cords of four-foot Wood. In their week's run they would drive seven 10,000-ton cargo ships from New York to the Panama Canal

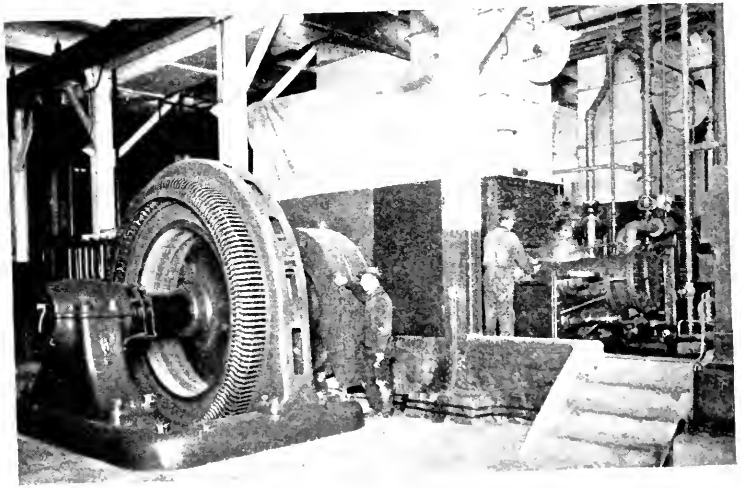

Fig. 6. The 2400-h.p. Grinder Motors Keep the Mill Power-factor at Unity. There are two grindstones driven by each motor and the motor load is closely regulated by the water pressure that is applied to the hydraulic jacks that force the wood against the stones. The motor design has pleasing lines without detracting from the appearance

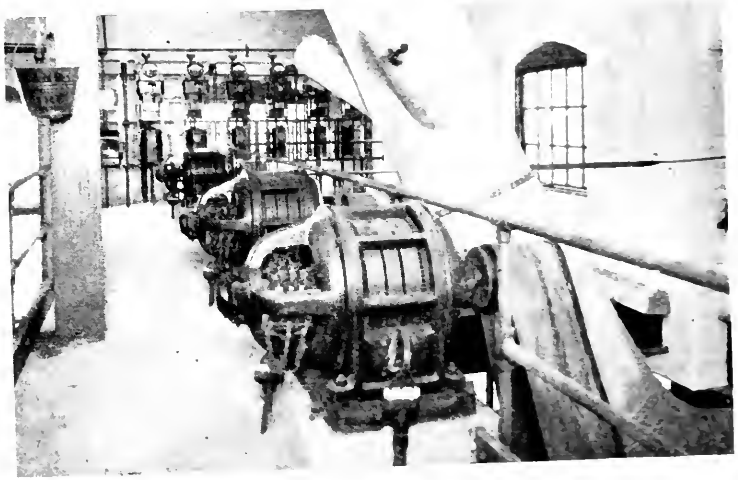

Fig. 7. Six 25-h.p. Wound-rotor Motors Drive 30 Deckers or Pulp Thickeners which Remove Nine-tenths of the Water from the Pulp. This water is returned to the grindstones

the blow pits for several hours until practically nothing remains but the silky unbroken fibers of cellulose.

When the stock leaves the digesters it is 92 per cent water and becomes 99 per cent water while being washed in the blow pits. It now goes to a 35,000 gallon stock tank which stores up enough to convert the intermittent discharges from the digesters into a continuous process beyond the tank. Horizontal shaft agitators in this tank keep the contents from settling.

From the tank a steady flow goes through a mixing box, which by the addition of white water from an extracting process further along doubles the volume. A rotary screen of the type called a knotter extracts the coarser clots and fiber bundles and a still further refinement takes place in the improved rotary meshed drum "first" screens which pass only the individual fibers through very narrow slits. The rejected material from the knotters and first screens passes through a "second" screen which returns the valuable portion to the main stream back of the first screens and sends the coarser parts to the wrapping paper department.

The stock now cascades down five steep meshed thickeners into tanks in which revolve partly submerged screen thickener drums.* The excess water falls through the inclined screens or passes to the inside of the drums, while the pulp adhering to the outside of the drums falls over the dams and flows to the soft stock tank below. The thickeners reduce the water flow from 2900 to about 400 gallons per minute which leaves the stock about the consistency of thin porridge. The extracted white water goes to a tank to be worked back into the system in various ways. The screens and thickeners are belt group driven with other miscellaneous machinery.

A sulphite soft stock tank, with a capacity of 45,000 gallons, is equipped with a horizontal shaft agitator to prevent separation. A small addition to this stock comes from two inclined "save alls" which give the white water tank overflow a last screening before it goes to the sewer. Leaving the sulphite pulp at the soft stock tank we will follow the preparation of the ground wood to a similar point.

Interest in the ground-wood department centers about the grinders, for here is the heaviest draft on electric power and the greatest material transformation, all carried on with relentless energy and yet with just that skill and delicacy that produces unvaryingly the balance between quality and quantity which goes so far to uphold the mill's production record.

Seven General Electric 2400-h.p., 2200-volt synchronous motors backed by their switchboards, oil switch cells, starting compensators and exciter motor-generator sets, form the most imposing array of power in the mill.

These synchronous motors, aside from their remarkably high efficiency of 96.2 per cent at full and 96 per cent at three-fourths load, are designed to allow for a strong leading power-factor even at fractional loads. As their load far outweighs all the induction motors combined, the power-factor for the mill is exceptionally high and is under perfect control.

Wood grinding furnishes an ideal load for synchronous motors as the grinders have light starting load when the pressure is relieved; they have a constant load characteristic regulated by an automatic device and the total load is so great that the power-factor for the whole plant is kept at unity. It is of interest to note that the induction motor load alone has a power-factor of 72 per cent.

These synchronous motors are started by reduced voltage tap compensators and the power-factor is controlled on the individual motors by their field rheostats. The motors are designed for 72 per cent leading power-factor at full load.

Each 2400-h.p. motor is direct connected to the end of a shaft that carries two 60-inch diameter by 54-inch face grindstones thus making twelve stones in all. The seventh set, which will make fourteen stones, is being installed.

The grinders are of the Watrous magazine type, i.e., the wood is fed into vertical chambers that reach to the charging floor where they are kept filled from wood bins that are in turn kept replenished by the conveyor system. The four-foot logs are laid in the magazine parallel to the shaft, making two compact stacks per stone in the magazines with the stone between them at the bottom. The logs that lie alongside the stone on either side are forced against the stone by hydraulic pistons until they are ground away. When the pistons have completed their strokes, they automatically withdraw, allowing more logs to fall into the vacant spaces, when the relentless forward travel of the pistons begins again. The withdrawal of the pistons is accomplished by the low pressure 50-lb. water system, while the grinding pressure is applied

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* See illustration on the cover of this issue of the REVIEW.

by the 190-lb. water pressure using, however, only about 150 lb. in service.

Without water the wood would burn and the stones would burst from heat, therefore, some 6000 gallons per minute of white water is flushed over the twelve stones, serving to bring the ground wood away as pulp which is over 99 per cent water. Even so the heat generated evolves a great amount of steam. This, however, is ejected by an ingenious system which leaves the department unusually clear. Projecting through the side of each magazine is a toothed wheel which is turned as the wood sinks toward the stone, its purpose being to register the cords of wood ground.

Provision is made for burring the stones at regular intervals by means of a built-in hydraulic burring lathe, without interfering with production, and a light burring at three hour intervals is said to give very uniform results. Each stone, consuming about 900 h.p., grinds 17 tons of air dry pulp per 24-hour day and the pulp is of such high quality that refining processes usually resorted to are omitted in this mill.

The pulp after leaving the grinders passes through inclined sliver screens having a large area, leaving the slivers on the surface from which they are raked by chain operated scrapers. The coarse residue is burned along with the bark and sawdust.

A tank holding 96,000 gallons receives the raw stock together with the return of useful stock from the second screens further down the line. Still more white water is added to the knotter mixing box before the stock goes to the four Improved Sherbrooks rotary screen knotters. Fiber bundles and other over-large units are washed off the upper inside surface of the drums and pass to the wrapper machine system as was the case in the sulphite department.

The stock now flows into long rifflers which are fitted with submerged baffles to arrest sand from the stones and other heavy impurities. Four improved rotary first screens further refine the stock while they discharge undesirables to the second screens for a rescreening. Throughout the process so far the water content has varied from $99\frac{1}{4}$ to $99\frac{1}{2}$ per cent as influenced by the addition of white water and extraction to the second screens.

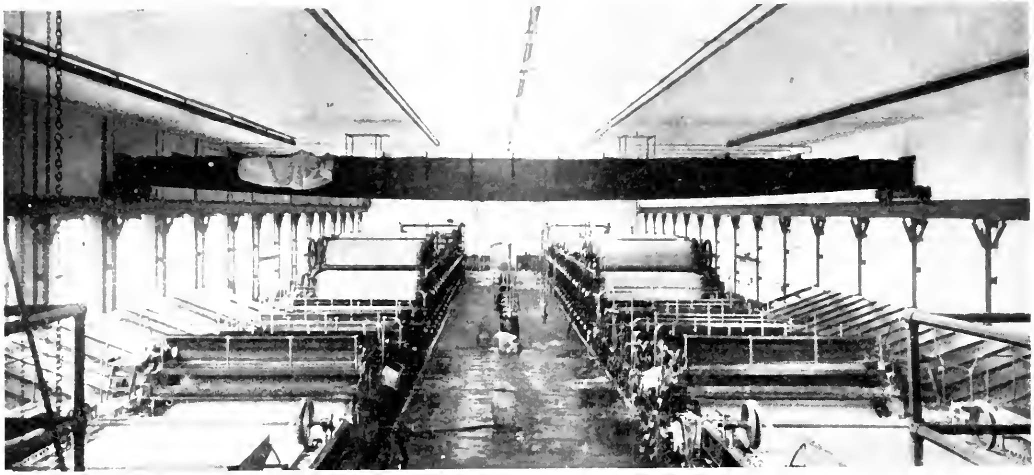

Fig. 8. Two of the Four 164-in. Bagley and Sewell Paper Machines make Paper at the Rate of 800 ft. per min. with an Ultimate Speed of 1200 Ft. per Min. Two more similar units are in the next room on the right. The "stuff" is poured on at the extreme foreground and 45 seconds later is reeled up as specification paper at the far end of the room. There is 600 linear feet of paper in process on each machine

A battery of thirty deckers thickens the stock by removing all but about one-tenth of the water. This is done by rotating meshed drums partly submerged in the stock. The water runs into the drum and away to the ground-wood white water tank, while the pulp left on the surface is scraped off and passes to the concrete cave-like ground-wood soft stock tank which holds 890,000 gallons, equal to 160 tons of stock if it were air dry. A steel tank outside is nearly ready to take 750,000 gallons of stock as an additional reserve. The ground-wood pulp is now advanced to the same relative point as the sulphite pulp.

A stream of pulp from each of the soft stock tanks is automatically regulated to a consistency of 96½ per cent water and brought to the mixing system where they are automatically regulated to mix in the desired ratio. Into the resulting flow is fed a thread of bluing to neutralize the natural yellow color of the pulp, and a trickle of alum water is added for a size. It is now pumped to the machine room and through the final screens thence to the mixing boxes where it is literally drowned in a flow of white water which amounts to 60,000 tons per day.

The introduction of this quantity of water which forms the major circulating system of the mill reduces the "stuff" to a consistency of two cups of dry pulp to the barrel, and this dilution is necessary to secure an even felting of the fibers in the early stages of the sheet formation.

It is the function of the four paper machines to form the sheets and remove this water down to a 10 per cent moisture content. The four paper machines are each about 350 feet long and they turn out 875 miles of paper a day as wide as a state road and at the rate of 36 miles per hour.

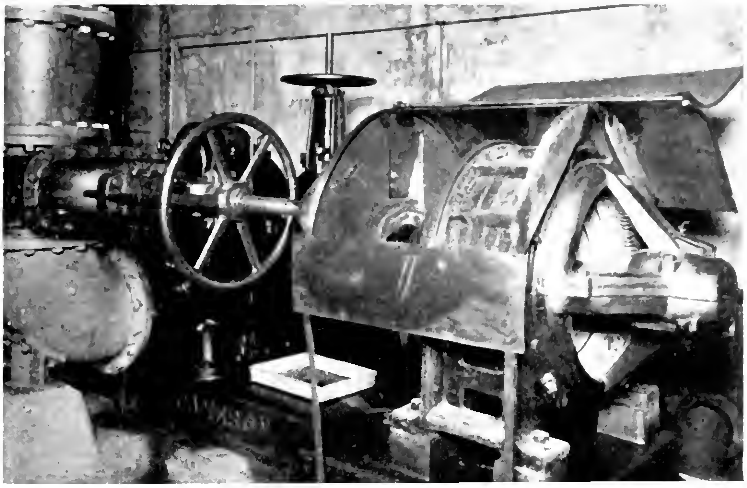

Fig. 9. The 100-h.p. Squirrel-cage Motor Which Circulates 35,000 Tons of White Water per Day from the Pulp Thickeners Back Over the Grindstones. Being located in a pit below the ground-wood mill, the motor is protected by a well designed removable shelter

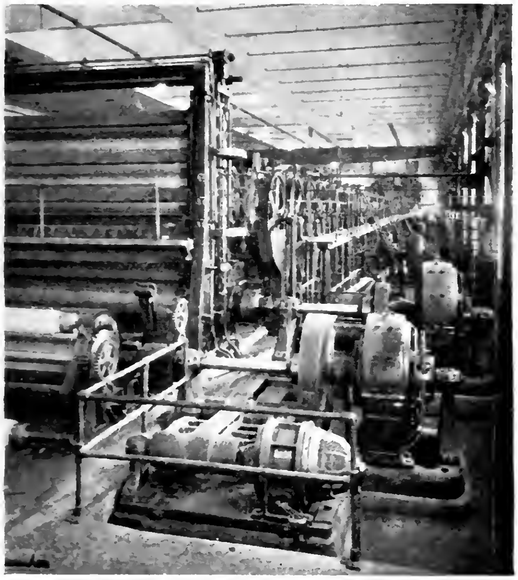

Fig. 10. View of One of the Paper Machines from the Dry End, Showing Several of the d-c. Units and their Accompanying a-c. Speed Control Units. The paper machine can be operated from 500 to 1200 ft. per min without losing the precise speed relationship between the nine sections

Each machine consists of nine independent precision speed regulated sections driven by the well known General Electric section drive.

The first section, the Fourdrinier "wire"—a fine brass wire mesh belt, receives the "stuff" in a stream 13 feet wide and ⅝ of an inch deep. In 50 feet of travel and within three seconds, most of the water has fallen through leaving a very wet sheet of paper which is peeled off the "couch" roll at over 800 feet per minute, passing unsupported over a gap to the second section. In three seconds 200 parts of water to one of pulp has become three parts to one and the watery web is called paper for the first time.

The wonder is that mass production of uniform quality can be carried out at such high speed, for 300 miles of paper has often been run off without so much as a pin hole to mar the sheet. Three gigantic wringers with solid granite rolls and weights on compound levers squeeze the sheet in succession compacting the fibers and removing a little water. Every section must run in linear feet a little faster than its predecessor and more precisely so as the paper dries and becomes less elastic.

The next section is long and high and consists of fifty 5-foot diameter steam heated drums over and under which the paper passes to expel by heat some 500 tons of water per day all told. The drums are all geared together and weigh nearly 400 tons.

The paper comes out containing 10 per cent water—the specified content for comfortable working on the printing presses, but it has a furry surface and is too thick.

The calender stack, a pile of ten polished steel rolls, now takes the paper in and out to the bottom where it emerges bright, smooth and printable.

The reel just beyond the calender rolls up the product into units weighing about 1½ tons. While not affecting the nature of the paper, this unit has also to be intimately tied in as to speed with the other sections. The entire course through the paper machine takes about 45 seconds.

These reels of paper are lifted by means of an electric parallel-motion hoist to stands, from which the paper is run through the slitter, which trims off the edges and slits the paper into two or more parts. The rewinder now rewinds the paper on paper tubes with metal ends that are adapted to the printing presses on which the paper will be used. It is usual to make two 73½-inch rolls, each weighing about 1400 lb. The rewinder is driven by a 30-h.p. motor with speed control by means of a rheostat in the field of an alternating-current motor-driven direct-current generator in the basement. The trimmings from the sheet and other "broke" resulting from various causes are put through a beater in the basement, which reduces the wet or dry broke to pulp that can be returned to the system at the machine chest.

The commercial rolls are now taken to the finishing room, where they are securely protected by heavy wrapping paper made from the rejections of the sulphite and ground-wood mill.

The General Electric sectionalized drive is operated in the following manner: In the basement below each paper machine there is installed a 500-kw. direct-current geared turbine generator set. The line voltage determines the rate of production on the paper machines and is 185 volts for 800 feet per minute, with a workable range from 500 to 1200 feet per minute. This voltage is controlled from the machine room by a chain-operated rheostat in the 500-kw. generator field. The turbine speed and the exciter voltage are held constant.

The motors driving the various sections have their fields energized by the 125-volt exciter. They are large, low-speed units designed for about 150 r.p.m. at 245 volts so as to avoid the interposition of gears. The couch roll and calender stack each take a 100-h.p. motor, while the presses each take a 50-h.p. motor, the dryer two 100-h.p.

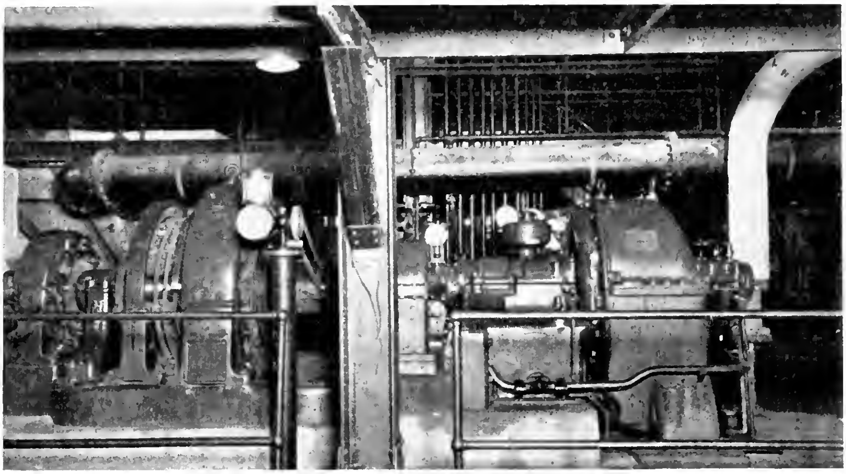

Fig. 11. The Motors for Each Paper Machine are Driven by a 500-kw. Turbine Set with Speed Control Through the Generator Field. The fields of the d-c. motors and their synchronous tie-in units are energized by the exciters on these sets. The turbines are operated at about 8-lb. back pressure and the exhaust steam carries 88 per cent of its original heat to the dryers

motors and the reel a 30-h.p. and the rewinder a 35-h.p. motor, all of the shunt-wound interpole type.

With the exception of the rewinder motor and the second motor on the dryer, each motor is accompanied by a 20-h.p. synchronous motor—or generator, as the case for the moment may be—and these synchronous tie-in units are all connected to a common three-wire three-phase bus to which nothing else is connected. Their fields are energized from the 125-volt exciter. These synchronous units are belted through cone pulleys to the direct-current motors, with the exception of the first dryer motor. In that case the cone pulleys are dispensed with as the speed of this unit is taken as par and the "stretch and draw" of the other sections are regulated to this base speed.

The effect of these synchronous units tied in as they are is similar to that of a great flywheel which can be neither delayed nor hurried. With all the motors running, any direct-current motor and the section it drives may be adjusted as to speed by moving the belt along on the cone pulleys. If the direct-current motor field strength is right, the synchronous unit will be simply idling, as indicated by its ammeter. Should the direct-current motor be inclined to run faster, the synchronous unit becomes a generator giving energy to the other similar units which for the time may be performing as motors. This puts a restraining load on the direct-current motor and effectually holds it in line. Conversely, if a direct-current motor is inclined to slow down, its attached synchronous unit would supply aid as a motor again, effectually holding the section in line.

These guide units can aid or hold back up to 40 h.p. each, and by occasional hand adjustment of the direct-current motor-field rheostats these exchanges of loads can be kept near to zero. Little attention is paid to the loads on these units, however, and the meters bear only a center mark and outside limit marks. Any change in the load on one unit affects the other eight by only one-eighth of the change. The belt shifter is brought through to the front of the machine, and the machine tender can change the speed of a section by a fraction of 1 per cent with the assurance that it will hold that place until he makes a further change.

When it is necessary to slow down or stop an individual section, the ordinary drum controller is resorted to, and its first step disconnects the synchronous unit from the common bus. Thereafter the section is controlled in the ordinary manner. After the section is brought up to normal speed the synchronous unit is tied in by pushing a button at the controller. Should the motor-overload circuit breaker open, it also disconnects the guide unit.

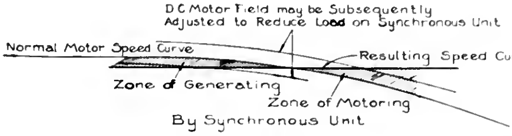

Fig. 12. The Speed of Each Section of the Paper Machines is Held Adjustably Constant by the Attached Synchronous-motor Guide Unit which may be Generating or Motoring to Hold the d-c. Motor in Line

After a complete shutdown, as, for instance, to put in a new Fourdrinier wire, all the sections can be restarted, brought up to speed and tied in as fast as the controllers can be handled. The tying in by the synchronous units does not require any special manipulation, as, being belted to their respective sections, they are always so closely in accord that there need be no delay on their account.

In this mill, the only 100 per cent electrified mill in the paper industry, may be found practical applications of electric power in many forms. The pumping of water and stock forms a large percentage of the load, and the combined output of the pumps is about 140,000 gallons per minute. A reference to the chart in Fig. 3 showing the water content in the materials as they pass through the various operations will indicate how important these units are. The grinding of wood on such a wholesale plan by electric motors, while not new, is so well worked out here that it is worthy of considerable study. Only in very recent years has it been considered feasible to grind wood other than by direct application of water power. The hundreds of widely scattered auxiliary units of every conceivable type could certainly not be located so conveniently or operated so economically with any other form of power transmission than electric motor drive. Finally, the sectional motor drive of the paper machines themselves is a very fine development of special industrial engineering and works out very much to the satisfaction of the trade.

Water Cooled Resistors

By H. F. Wilson

Railway Equipment Engineering Department, General Electric Company

The author describes the large capacity water resistors designed for use with the electrical equipment of the cargo boats of the Emergency Fleet Corporation and for similar heavy duty service.—Editor.

Very large capacity resistors are often required in starting large machines, such as induction motors under load and for limiting the load on certain machines in a large network system when short circuits or overloads occur. As a rule the large capacity is only needed for a short time so that a resistor with high thermal capacity is the most desirable. In order to keep the weight and size of such resistors down to reasonable proportions, the resistance units are placed in water. The capacity is further increased if the water is circulated.

The resistance unit used in a resistor of this type must be made of a material which will not corrode in the water or be easily affected by electrolytic action. It must also have a low temperature coefficient and a fairly high specific resistance so that the amount of material necessary will not be excessive. The cross section should be such that the maximum possible surface of metal is exposed to the water.

Of the common medium priced metals, monel metal seems nearest to meet the above specifications. The resistance of this metal is approximately 0.00002 ohm per cubic inch against 0.00000069 ohm for copper. Its temperature coefficient averages approximately 0.002 as compared with 0.00393 for copper.

Two general types of water cooled resistors have recently been built, one using a continuous circulation of water, and the other using a large tank of water, the amount of water being automatically held between two safe levels.

The water resistor No. 1 is of the first type and is shown in various views in Figs. 1, 2 and 3. This resistor was designed to be used in the secondary circuits of the induction motors used for driving the Emergency Fleet Corporation cargo boats.

The assembled view of this resistor is shown in Fig. 1. In Fig. 2 it has one side removed showing the assembly of the insulating tubes and terminal plates. Fig. 3 shows the various internal parts of the resistor.

As can be seen from these photographs the resistor consists of three legs, each leg having a resistance unit made up of 12 spirals of monel metal. The total resistance of the unit in the sea water at 20° deg. C=0.10 ohm. The three units are installed in three separate water-tight containers built up of tubes of suitable insulating material, each container consisting of two tubes spaced by a metal ring. A tube, which has been used to good advantage for ship work, is one made of treated wooden staves covered with varnish treated paper.

The object of separating the insulating tubes is to secure electrical creepage between the ring castings, to which the high sides of the resistor units are attached, and the top castings, carrying the manifold for the water, as the difference of potential between these two points may be several hundred volts.

The center or ring casting also serves for the outside connection from the resistors to the large contactors which cut the resistance in and out of the circuit.

Pure rubber gaskets are used to prevent water leakage between the ends of the tubes and the various castings, the parts being securely held together by retaining rod bolts. Each unit being capped with a separate casting, the tubes can be properly and tightly seated on the gaskets by the adjustment of the retaining rod nuts.

The twelve spiral resistances are supported by a central standard or post of wood, thoroughly impregnated with moisture-proof material which resists any detrimental action of salt water. The wood is bolted at the lower end to the frame base casting and is supported at the top by the brass ring which spaces the sections of the insulating container.

The individual spirals are prevented from sagging by cross pins made of wood. These cross pins are carried through holes in the standard and are secured by the same screws which fasten the spirals in place. The twelve spirals are connected in series and permanently tied together by copper straps riveted and brazed to the monel metal.

For the cooling system the sea water is pumped through a pipe main into the base casting where it distributes through the three containers and resistor units, discharging through a manifold provided with three apertures at the top, the manifold being connected to a discharge pipe.

Three hand holes are provided in the brass casting to assist in assembling the resistor units as well as to permit of inspection of the interior or removal of sediment which may accumulate. The hand holes are capped with steel plates lined with thin sheet zinc, the zinc preventing the wasting away of the steel or iron from electrolytic action between it and the monel metal resistor units, the zinc rather than the iron being attacked. The zinc will eventually be eaten away and must be renewed.

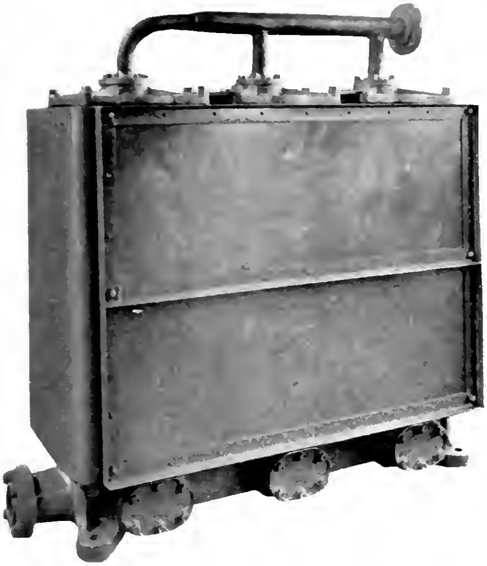

Fig. 1. A Completely Assembled Water Cooled Resistor of the Continuous Water Circulation Type

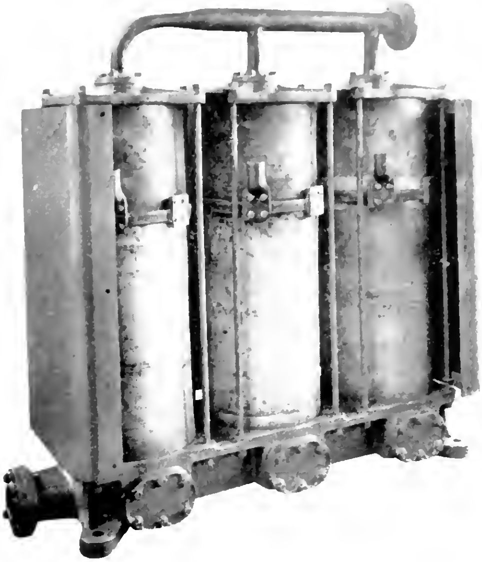

Fig. 2. The Water Cooled Resistor shown in Fig. 1 with the Cover Removed

The complete resistor is shrouded by a sheet metal guard to protect the insulation tubes from injury and to prevent anyone coming in contact with the live parts.

As used with the induction motors, this resistor is only in during starting and reversing, being "shorted" out during normal running. The maximum duty required of it,

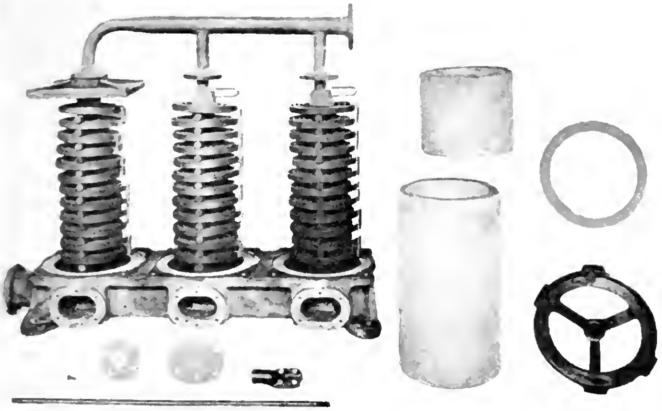

Fig. 3. Partially Dismantled Resistor of the Type shown in Figs. 1 and 2

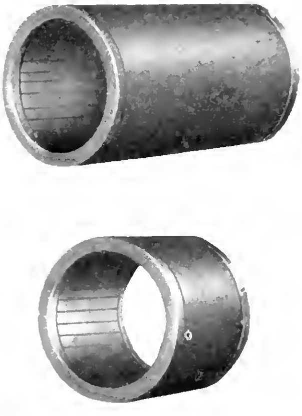

Fig. 4. Insulating Tubes for the Type of Resistor shown in Figs. 1 and 2

which occurs during a reversal at full speed, calls for the following currents per phase:

2730 amperes for 15 seconds.
2730 amperes decreasing gradually to 2200 amperes in 10 seconds.
2200 amperes decreasing gradually to 1700 amperes in 4 minutes.
1700 amperes decreasing gradually to 940 amperes in 7 minutes.

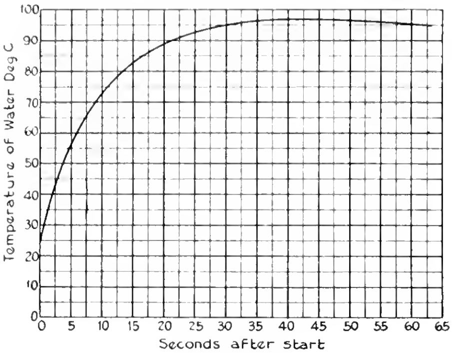

Fig. 5. Curve of Water Temperature for the Type of Resistor shown in Fig. 1 during the reversal of a ship at full speed

The resistance of each leg as stated previously equals approximately 0.10 ohm at 20 deg. C. or 0.12 ohm at 100 deg. C.

A circulation of 100 gallons of sea water per minute is maintained through the resistor while it is in service. A heat run at the above currents was made on one of these resistors and a thermostat placed in the water at the upper end of the middle compartment. The curve in Fig. 5 shows the temperature of the water for the first 60 seconds, the temperature gradually decreasing from this point to the end of the run.

A monel metal coil similar to the ones used in this resistor was tested in a jar of water to obtain the characteristics of the metal. The coil was located 4 inches from the bottom of a 30-gallon porcelain jar 24 inches deep and 19 inches in diameter. This jar was filled to within 1 inch of the top with water. The resistance of the coil at 20 degrees was 0.0078 ohm and at the boiling point of water 0.01 ohm. The radiating surface was 105 square inches.

Various currents were held until the temperature of the metal became constant which was after the water boiled. The resistance of the coil was read and from this the temperature calculated.

Curve A, Fig. 6, shows the temperature of the metal for various watts per square inch. For comparison Curve B shows the temperatures obtained in air for various watts per square inch. These curves show that approximately one hundred times the watts radiated in air can be radiated in water. Curve C shows the time necessary for the water to boil for the various loads. The watts per square inch are calculated from the hot resistance.

This type of resistor using monel metal units has proven very satisfactory in service and should have a considerable field wherever large induction motor drive is used.

The second type of resistor, that using a large tank of water, has to date been used for load limiting resistance. The water resistors Nos. 4, 5, 6 and 7 are included in this type.

The first installation of these is in connection with 250-volt, three-wire converters for the Kansas City Light & Power Company. The water resistors Nos. 4 and 5 are used with a 2250-kw. converter and have a capacity of 18,000 amperes, twice the rating of the machine. The resistance of the water resistor No. 4 is 0.00409 ohm and of the water resistor No. 5, 0.00967 ohm.

The water resistors Nos. 6 and 7 are used with a 1500-kw. converter. The water resistor No. 6 is connected in the positive side and has two steps of resistance, 0.00153 ohm in the first step and 0.00593 ohm total. The water resistor No. 7 is connected in the negative side and has 0.00153 ohm in the first step and 0.01303 ohm total. In normal operation all the resistance is "shorted" out by contactors. If the load on one side increases beyond a certain point the first step of resistance on that side is cut in. If a balanced overload occurs the first step on each side

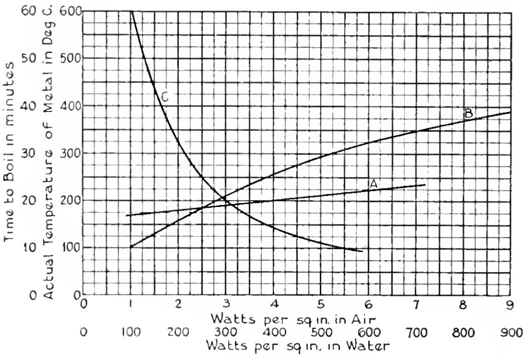

Fig. 6. Curve of the Temperature of a Monel Metal Coil at Various Watts per Square Inch in Water and in Air

is cut in. If these first steps do not limit the load sufficiently the neutral wire is opened and one of the larger steps cut in. In case of a short circuit at or near the busses all the resistance is cut in and this acts as a load directly across the generator. In the case of the water resistors Nos. 6 and 7, the current will be limited to 12,000 amperes, twice the normal rating of the machine. These resistors must therefore be capable of carrying this current practically continuously.

Fig. 7. Water Cooled Resistor of the Tank Type, showing the Main Terminals and Automatic Cutoff

The water resistor No. 6 is shown in Figs. 7, 8 and 9. These views show the simple construction of the resistor, it consisting primarily of a steel tank, the resistance unit and the water regulating devices.

Fig. 9. Interior View of the Resistor shown in Fig. 7

The tank is made of steel, the sides being in two parts, welded together and then welded to the bottom. Insulated busbars extend through and are fastened to one side.

As shown in Fig. 7, a sylphon regulator is attached to one end. This is adjusted so that fresh water will be admitted when the temperature of the water inside approaches the boiling point. The water will continue to flow, running out through the overflow pipe on the other side, until the temperature is reduced to a safe value.

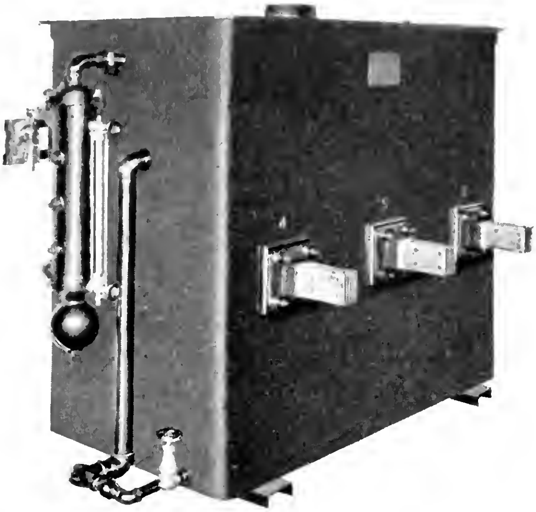

Fig. 8. The Water Gauge End of the Tank Type of Water Cooled Resistor shown in Fig. 7

As shown in Fig. 8, a safety water column and gauge is mounted on the other end of the tank. The gauge indicates to the station operator the level of the water. If the level becomes too low the float in the water column operates, opening an interlock which opens the line contactors.

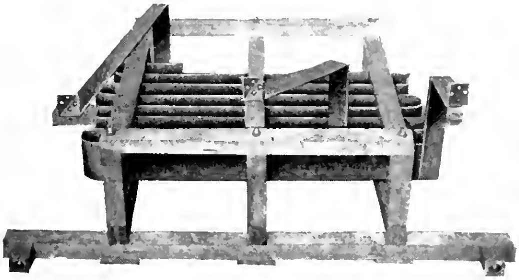

Fig. 10. Resistance Unit Removed from Its Position in the Tank as shown in Fig. 9

An angle iron is welded along the outside upper edge of the tank to which the top is bolted. A pipe outlet is provided in the center of the top to allow the steam to escape.

Fig. 9 shows the inside of the tank and Fig. 10 the resistance unit removed from the tank. This unit consists of a wooden support, the monel metal resistance and the copper busbars which extend from the ends and tap on the monel metal to the large insulated busbar terminals which extend through the side of the tank.

Fig. 11. Another Water Cooled Resistor of the Tank Type (similar to that shown in Fig. 7)

The monel metal resistance is made of strips of metal brazed together to give the length necessary for the resistance. This is bent as shown in the photograph to give 7¼ convolutions.

The water resistor No. 7 has the same dimensions as the water resistor No. 6 except it is wider and the resistance unit is correspondingly wider, having 15½ convolutions. The total resistance equals 0.013 ohm with a tap equal to 0.00153 ohm. It has two pipe outlets for the escape of the steam. Fig. 11 shows this resistor.

This resistor holds 820 gallons of water when filled up to the overflow pipe. Based on 100 per cent efficiency and assuming the water at 20 deg. C. it requires 21.1 kw. to heat one gallon 80 deg. or to the boiling point. Theoretically, therefore, neglecting the thermal capacity of the tank, 17,300 kw. can be dissipated for one minute before the water reaches boiling temperature; and 1870 kw., the normal capacity of the resistor, for 9¼ minutes. Due to the thermal capacity of the tank and other parts of the resistor, an actual heat run at 12,000 amperes (1870 kw.) shows that it requires between 11 and 12 minutes to boil the water. In normal operation, however, the sylphon regulator operates before the water boils and cold water is admitted holding the temperature below the boiling point.

It is interesting to compare the size and weight of this resistor with one made of cast iron grid resistors and air cooled, of the same capacity. The water resistor No. 7 weighs 2650 pounds without water and 9500 pounds when filled with 820 gallons of water. Its volume is 150 cubic feet.

If standard cast iron grid resistors were used, it would require approximately 25,000 pounds of material and 300 cubic feet of space without any supporting frame.

If these resistors were arranged for maximum forced ventilation, the amount would be decreased to approximately 10,000 pounds and 120 cubic feet without supporting frame. The volume including supports with the ventilated grids would be approximately the same as the water cooled resistor, but a blower would be required capable of delivering approximately 15,000 cubic feet of air per minute requiring 11 or 12 horse power. Automatic means for starting this blower when power came on the resistor would have to be provided.

Although the volume and weight (including water) of the water cooled resistor and the ventilated air cooled resistor are approximately the same, when it is noted that the water cooled one requires only 2650 pounds of solid material compared with 10,000 pounds in the air cooled one, the advantages of the former can be appreciated.

It can be seen from the above that for large capacities such as necessitated the design of these resistors, this type of water cooled resistor should be superior to the air cooled one from the standpoint of cost, maintenance, weight, volume and simplicity.

The 40,000-kv-a. Shawinigan Falls Waterwheel Generator

By J. Ralph Johnson

Contract Service Department, General Electric Company

The 40,000-kv-a. waterwheel generator which was placed in operation at the Shawinigan Falls Development, Quebec, Canada, is notable not only on account of its size but for its other features of ultra-modern design. The following article describes the design and construction of the machine, and the illustrations show the various stages of its installation. In a forthcoming issue of the Review we hope to publish a summary of the acceptance tests of this huge waterwheel generator unit whose rotating element alone weighs 251 tons.—Editor.

The 40,000-kv-a. waterwheel generator at the Shawinigan Falls Development of the Shawinigan Water & Power Co. (Quebec, Canada) has been in operation since October of last year and is the largest machine of this type installed by the General Electric Company to date.

The unit is of the vertical type with direct-connected exciter, and is designed to deliver normally 40,000 kv-a. of three-phase current at 0.75 power-factor, 60 cycles and 11,000 volts, the speed being 138.5 r.p.m. It will also operate on 25 per cent overload (44,000 kv-a.) at 0.85 power-factor for two hours without undue heating, and may, if required, operate continuously at 12,000 volts and full-load current. At full load and unity power-factor the efficiency is 97.5 per cent and the regulation 15 per cent.

The rotating parts of the generator and turbine are carried by a thrust bearing supported by a deck or bracket which spans the top of the stator frame. The generator and turbine shafts are connected by a solid coupling and there are two guide bearings, one between the thrust bearing and the rotor, the other a lignum vitæ bearing above the waterwheel.

An interesting feature of this installation is that the operating floor is level with the top of the stator frame. This construction gives ample space round the generator on the main floor and provides a convenient means for dealing with the exhaust air from the generator in the annular space beneath this floor, as the air may either be utilized to heat the generator room in winter by opening up steel trap-doors in the floor, or it may in summer be ejected outdoors through windows in the outer wall beneath the main floor.

A point of interest external to the machine is the absence of low-tension switches; the generator is connected directly to the transformer primary windings through the low-tension bus. Disconnecting links are provided so that the machine may be isolated if necessary, and oil circuit breakers are installed between the transformer secondary windings and the high-tension bus for 100,000-volt service.

Stator Frame and Core

The stator frame is of cast iron and is divided vertically into four 90-degree sections in order to facilitate transportation and handling. The outside diameter is 30 ft. 4 in. and the height 5 ft. 10 in. The stator core was built up on site in order to avoid the continuous vertical joints which occur in cores which are assembled in the factory and shipped in sections.

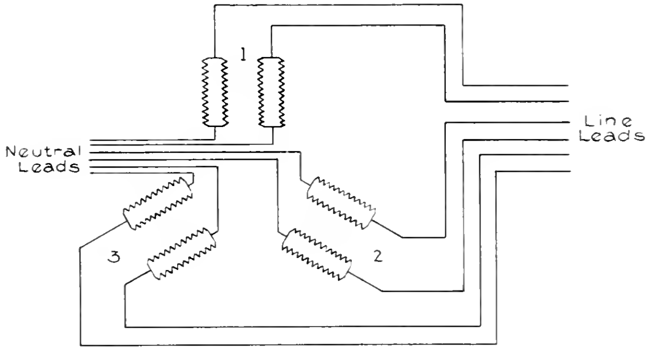

Fig. 1. Schematic Diagram of the Armature Winding

Stator Winding

The armature winding is three-phase, uniformly distributed round the core, and the coils have a fractional pitch. Thus a voltage wave closely approximating a sine wave is obtained and higher harmonics are eliminated. This was confirmed by an oscillogram of the voltage wave taken after the machine was in operation.

The coils are of the mica insulated type, mica tape having been employed both for the insulation between turns and for coil insulation. A sticker compound was used between the layers of the coil insulation, and all air spaces were eliminated from the coils during the vacuum process of impregnating them with insulating compound. This prevents possible destruction of the mica insulation by ionization and permits the compound to fill completely the interstices of the coils. An outer armor of horn fiber was moulded on the coils thus obviating the use of slot lining. When cold the coils are perfectly solid and it is customary to heat them slightly in order to render them flexible, before inserting or removing them from the slots. Wedges of maple wood secure the coils in the slots.

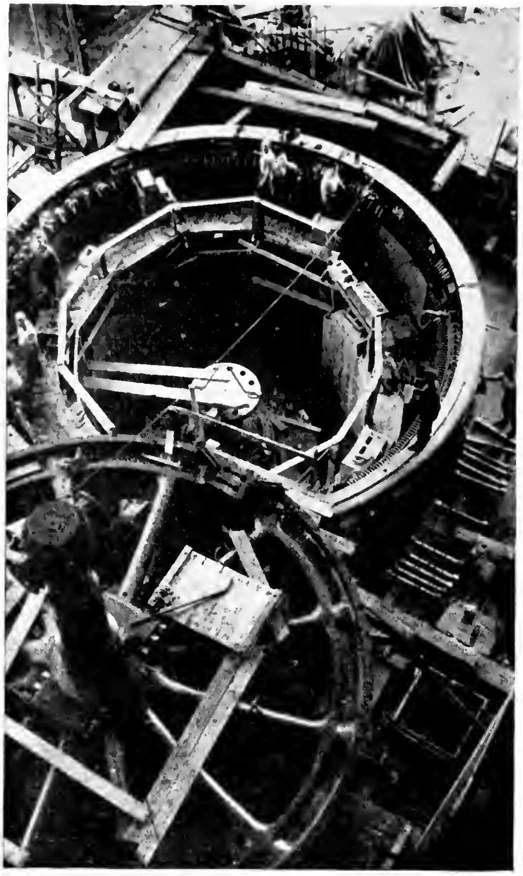

Fig. 2. Layout of the Work During Construction

The copper conductor is subdivided into wires of rectangular section, cotton covered; by this means eddy currents in the copper are considerably reduced and the coil forming process is facilitated.

The phases are effectively distributed round the core as there are four circuits from line to neutral in each phase, giving 12 internal circuits in the winding, the armature reactance being approximately 20 per cent. Six line and six neutral leads are brought out from the machine as shown in Fig. 1; this permits the use of both the differential and the split conductor method of generator protection, since current transformers may be mounted on the two leads of each line. The neutral is grounded through a high resistance and ground relay.

Steel bracing rings attached to brackets on the stator frame are employed for supporting the ends of the coils which are securely tied to the rings with prepared cord. The supporting rings are well insulated with mica and varnished cambric thus providing in addition to insulation a mechanically protective cushion for the coil ends. This method of bracing the coils gives ample strength against the distorting effect of short circuits and allows expansion and contraction of the coils due to temperature changes.

Series connections between adjacent coils are made by means of soldered joints and copper clips, while pole connections are made of flexible conductors similar in section to the stator conductors and connected to the latter by the same type of joint as the series connection. All joints are well insulated with varnished cambric. The phase connections are made to flexible bus rings which run over the top of the end connections, from which they are separated by wooden spacers and to which they are tied for support. The bus rings are also braced against one another by means of wooden spacers and cord.

During the winding of the armature six temperature indicating coils were inserted in pairs of slots that are spaced 120 mechanical degrees apart. Four were placed between coils in the slots and two were placed at the bottom of the slot between the lower coil and the core iron. Armored cables connect the different temperature coils with a protective device on the stator frame which serves to bring any temperature coil to ground potential, by breaking down its insulating disk cut-out, in case the coil exceeds a definite potential which would be unsafe for the instrument or switchboard operator.

otor

The rotor spider is made of cast steel and onsists of three wheels each made up of two emi-circular sections bolted together at the ub and linked together at the rim by shrink eys. The rim, arms and hub of each section re cast solid. Some manufacturers have aised objection to this type of rotor contruction in large units owing to the difculty of obtaining reliable castings. If, owever, proper care is taken in annealng, testing of samples, and keeping stresses t overspeed within half the elastic limit, ntirely reliable castings can be and have een made. The rotor with the rim cast olid with the spider offers certain advantages ver the laminated rim type. In the former he rim stresses are relieved by the arms, and he rotor balance will not be disturbed while he machine is in operation as might be the ase where a laminated rim "settles" on the hrough-bolts while running.

A one-inch space is left between the wheels y making the hubs slightly wider than the ims; this allows ventilating air to pass along he spider, between the pole pieces, and out hrough the stator ducts. Fans are provided n the upper and lower faces of the rotor im, to draw the cooling air from the pit eneath the generator. Small circular blocks erve to keep the rims separated and supported at intervals, and the three wheels re tied together by vertical bolts through ight arms of each spider.

Fifty-two pole pieces with coils of edgeound copper strip are assembled on the pider by means of V-shaped dovetails and re held securely in position by two taper eys. This fit is designed to withstand tresses due to double normal speed without ny slackening and without exceeding half he elastic limit of the material.

The shaft is made of forged steel and has a olid forged flange which is bolted to the aterwheel shaft flange for coupling. The oupling bolt holes were reamed on site thus nsuring proper alignment of the two shafts.

The total weight of the complete rotor is 01 tons and the flywheel effect (WR^2) is 5,034,000 lb. ft.^{2}

The kinetic energy stored in the rotating arts is enormous and it would take a considerable time to bring the machine from ormal speed to rest unless some method of raking were provided. A mechanical braking ystem was therefore installed which serves he double purpose of shutting down the achine quickly and of holding the rotor at rest against possible leakage past the waterwheel gates when the Johnson valve is not closed.

Six brakes are mounted on concrete pillow-blocks beneath the under surface of the rotor rim. Each brake has two cylinders with pistons 6 in. in diameter and a shoe is mounted on each pair of pistons. The cylinders are connected to each other and to a tank reservoir containing oil, and normally the tank and interconnecting pipes are full of oil. In order to apply the brakes when the machine is running, air at 75 lb. pressure is introduced to the tank by means of a motorman's valve mounted on the operating floor.

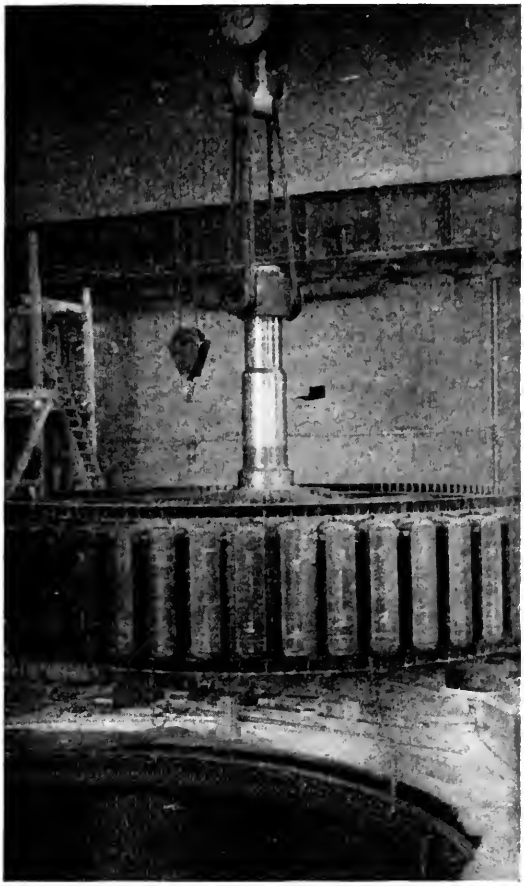

Fig. 3. Completed Rotor Suspended From Crane by the Lifting Trunnion

The air is introduced and exhausted periodically as the machine slows down, in order to avoid excessive wear of the brake-shoes the pressure is transmitted by the oil to the

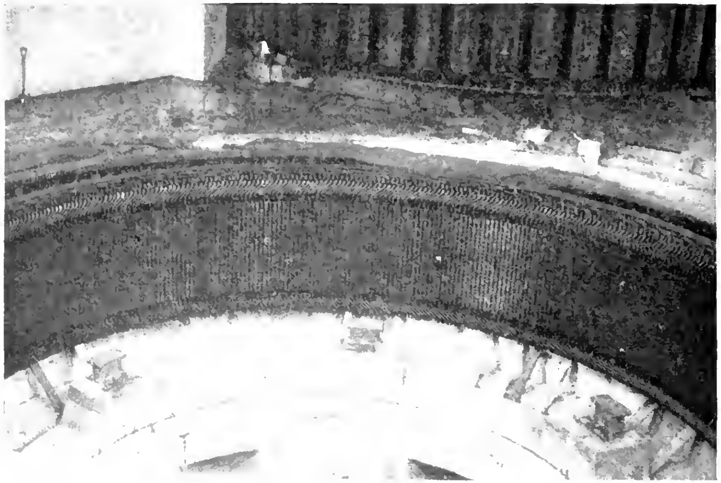

Fig. 4. Completed Armature Winding and Three of the Brake Blocks

Fig. 5. Assembling the Rotor Spider

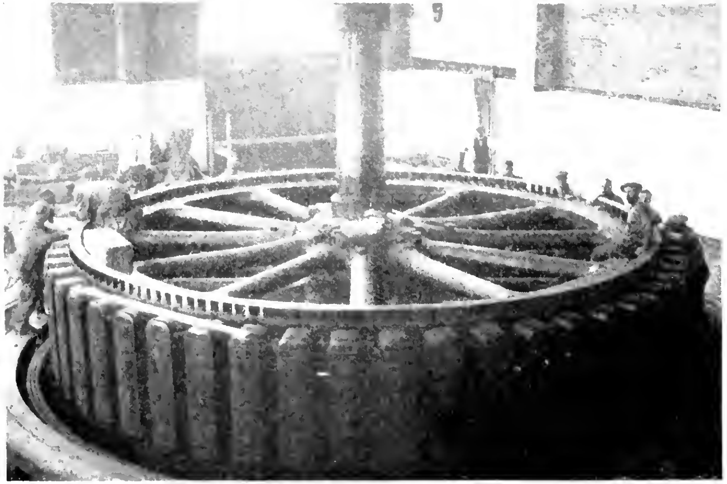

Fig. 6. Lowering the Rotor Into the Stator by Means of a Crane

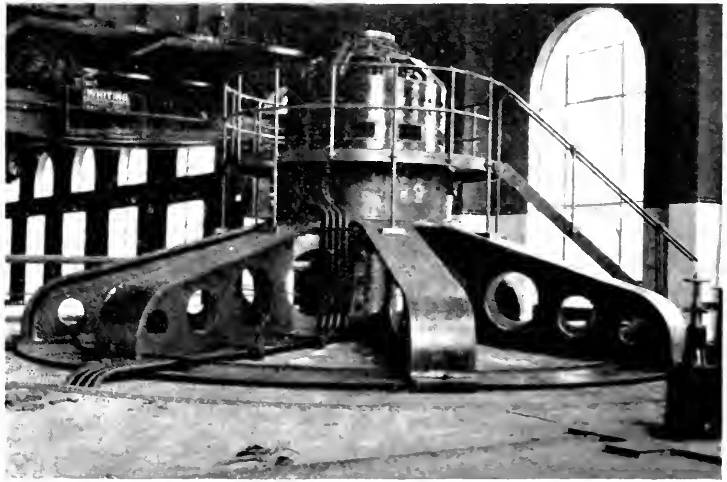

Fig. 7. The Completed Generator

cylinders, and the brake-shoes mounted on each pair of pistons are made to bear on the rotor rim.

The brakes may also be used when necessary as jacks to raise the rotor from the thrust bearing for inspection or repair purposes. In this case a hand-operated oil pump is used. This pump is connected to a three-way cock at the bottom of the tank reservoir; the tank is shut off and an oil pressure of about 1500 lb. is built up in the system by the hand pump. The brakes raise the rotor off the thrust bearing and shims are inserted between the brake shoes and the cylinders so that the rotor will remain raised when the oil pressure is removed.

Upper Bearing Bracket

The upper bearing bracket is made of cast steel. It consists of two sections bolted together forming at the center the housing for the upper guide bearing, and the base for the thrust bearing oil bath. The end of each bracket arm rests on top of the stator frame and is provided with a lip in which there are three bolt holes. Two of these are for jack bolts which are used to raise the bracket so that shims may be inserted between the lip and the stator frame for fine vertical adjustment of the rotating parts. The third hole is for the holding-down bolt. In order to insulate the bearings from ground, mica pieces are placed on the stator frame beneath the bearing-bracket shims and insulating washers and bushings are employed on the holding-down bolts. All pipes connected to the bearings have an insulated union so that the possibility of shaft circulating currents, with consequent pitting of the bearings, is eliminated. Cast steel was used in this bracket in preference to cast iron because for a given deflection a much lighter casting may be used thus allowing a more shallow structure, and rendering it possible to lead the drain pipe from the oil pan beneath the upper guide bearing, over the top of the stator frame, instead of employing a rotating pan which has to be drained down through the rotor.

Bearings

The generator guide bearing is of the standard babbitted type with grooves for distributing the oil, while the waterwheel guide bearing is of the water lubricated lignum vitæ type.

The General Electric spring thrust bearing is used on this machine and is designed to carry a load of 360 tons, this figure including the hydraulic thrust of 110 tons. The bearing consists essentially of a spring-supported stationary babbitted plate and a highly polished hard grey cast-iron rotating plate. The stationary plate has radial oil grooves and a radial saw-cut which prevents any tendency of the plate to dish under increased temperature. It is supported on a large number of helical springs loosely pinned to a base plate which is dowelled to the machined face of the upper bearing bracket. The flexibility of this support allows the plate to conform to the natural alignment of the shaft thus preventing excessive local pressures in the bearing and allowing the maintenance of an oil film between the bearing surfaces. The rotating plate is dowelled to a thrust collar which is keyed to the shaft, and a split retaining ring in a circular keyway near the top of the shaft is bolted to the thrust collar. The bearing operates in an oil bath and the heat generated is taken up by the oil as it passes by centrifugal action between the bearing surfaces. Heat is also transmitted to the oil through the metal of the bearing plates. The heat is removed from the oil by the circulating water in a stack of cooling coils immersed in the oil bath. In order to maintain the oil clean it is circulated slowly and filtered. Clean oil is pumped from a filter tank on the ground floor to an upper tank above the level of the machine. From the latter tank the oil is piped to the guide and thrust bearings, thence to a common drain which returns to the filter tank. If by any chance the oil pumps (one of which is in reserve) develop trouble and have to be shut down, the generator may still run if the thrust bearing oil supply line is shut off, as the storage tank can supply the guide bearing for several hours and the cooling coils will maintain the oil in the thrust bearing at normal temperature.

TABLE I

PRINCIPAL DIMENSIONS AND WEIGHTS OF 40,000-KV-A. GENERATOR

Outside diameter of stator	30 ft. 4 in.
Diameter of rotor	25 ft. 3 in.
Height of stator frame	5 ft. 10 in.
Overall height from coupling to top of exciter	21 ft. 8 in.
Maximum height above operating floor	13 ft. 6 in.
Weight of shaft	32,000 lb.
Weight of rotor spider	240,000 lb.
Total weight of rotor with shaft	402,000 lb.
Weight of waterwheel runner	100,000 lb.
Hydraulic thrust	220,000 lb.
Operating load on thrust bearing	720,000 lb.

Excitation

A 220-kw. 250-volt exciter, shunt wound, with commutating poles and designed for service with an automatic voltage regulator is direct connected to the top of the generator shaft. The exciter armature spider is provided with a recessed lower face which fits over the main shaft and is bolted thereto. The leads from the generator field pass along an arm of the rotor into the shaft and up through a central hole to the slip rings above the exciter.

No rheostat is employed in the generator field, voltage control being effected with the exciter field rheostat. The rheostat losses are thus cut down to a minimum.

Direct-Current Locomotives for the Imperial Government Railways of Japan

By A. Bredenberg, Jr.

Railway Equipment Engineering Department, General Electric Company

The United States has been the great proving ground for railway electrification. There are here present a combination of the talent necessary, the manufacturing facilities required, and the reasons for electrification which are: the high cost of maintenance, labor, and fuel for steam operation; the limitations placed on greatly increased tonnage movement by inadequate parallel trackage, heavy grades, or severe climatic conditions; and the smoke nuisance in tunnels and at terminals. All the types of electric systems that showed promise have been tried out on a practical scale. As the result, the governments of England, France, and Holland have officially accepted the high-voltage direct-current system for their electrification programs; and installations are in operation, or contracted for, in Spain, South Africa, South America, Australasia, Mexico, and Japan. The following article details in particular the control equipments of the locomotives for the initial 1500-volt direct-current electrification in Japan.—Editor.

Two direct-current locomotives have recently been completed for the Imperial Government Railways of Japan. The track gauge of this railway system being 42 inches, considerably smaller than is standard in this country, necessitated a very compact design widthwise. This narrower gauge also lends added significance to the locomotive weight, 132,000 lb., which is carried entirely on the drivers. The tractive power is furnished by four motors each directly geared to a driving axle. Thus equipped, the locomotives are capable of hauling 670 tons up a one per cent grade at 15 miles per hour.

For the present, the locomotives will operate on the Tokaido line between Tokyo and Yokohama at 1200 volts. Eventually, they are to operate on the extension of this electrification at 1500 volts direct-current.

While the narrow gauge prevented the use of parts exactly like those in use in this country, where the gauge is 4 ft. 8½ in., the design is very similar to the design of locomotives used successfully on various American railroads.

The running gear consists of two-axle main trucks supporting the superstructure on centerplates. The truck has cast-steel transoms which carry a hollow centerplate and have openings provided with collars at the sides held against the motors in such a manner that air delivered by a fan in the cab passes down through the centerplate into the hollow transom and thence to the motors.

Equalization of the load on the journals is provided for by semi-elliptic springs and by coil springs in series with the leaf spring which tends to produce an easier riding truck.

The width of the locomotive is determined by a strict clearance line, and by the necessity

TABLE I

PRINCIPAL DATA OF LOCOMOTIVE

Trolley voltage	1500, 1200, or 600 volts
Track gauge	42 in.
Length over bumpers	37 ft. 2 in.
Length over cab	29 ft. 0 in.
Total width	9 ft. 4¼ in.
Total height (Trolleys locked down)	12 ft. 10 in.
Total wheel-base	26 ft. 0 in.
Rigid wheel-base	8 ft. 6 in.
Diameter wheels	42 in.
Weight locomotive (all on drivers)	132,000 lb.
Weight per axle	33,000 lb.
Number of motors	4
Tractive effort; one-hour rating (1500 volts)	17,800 lb.
Tractive effort; continuous rating (1500 volts)	17,300 lb.
Starting tractive effort; 25 per cent coefficient of adhesion	33,000 lb.

for keeping within such clearance lines on certain specified curves.

The draft and buffing are taken care of by what is known in this country as European type draft gear and buffers; although the details are in accordance with the Imperial Government Railways' standards. Provision is made for substituting American type draft gear which eventually may be the Japanese standard.

The construction of the platform of structural channels and plates follows the method used in this country.

The cab is of the box type which lends itself best to housing the type of equipment required by the necessity for operation at the same speed on 600 volts as on 1200 volts.

The control equipment for these locomotives is of particular interest as it embodies several new features of design. Outstanding among these features are a new form of high-speed circuit breaker for locomotive service and a new type of electro-pneumatic contactor unit for controlling the motor and resistance circuits.

Operation

These locomotives are designed to operate on 1500, 1200, or 600 volts. They may be operated either in single unit or with two locomotives in multiple. On 1500 and 1200 volts the same control and motor connections are used, the speeds obtained being approximately proportional to the voltage. On 600 volts the motor and resistance connections are commutated so that the same speed is obtained on 600 volts as on 1200 volts.

Fig. 4 illustrates the master controller used. It has two speed combinations with ten steps in the first combination and eight steps in the second. This gives an ample number of operating steps for a locomotive of this size and allows the torque increments between steps to be so proportioned as to obtain smooth acceleration. The first nine steps in the first combination and the first seven steps in the second combination are resistance steps, i.e., with resistance in series with the motors. The 10th and 18th steps are running steps with all the accelerating resistance short circuited.

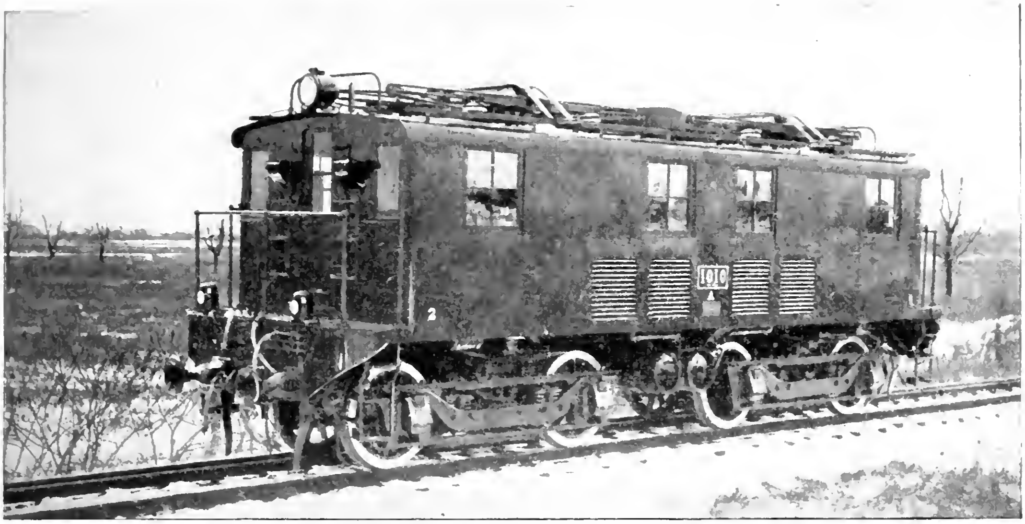

Fig. 1. 1500/600-volt Freight Locomotive for Imperial Government Railways of Japan

The control voltage for energizing the master control circuits is obtained from the midpoint of a dynamotor with a 2:1 voltage ratio. This dynamotor is operated by trolley voltage. Thus with 1500 volts on the trolley the nominal control voltage is 750 volts and with 1200 volts on the trolley it is 600 volts. For operation of the locomotive on 600 volts, the control circuits are disconnected from the dynamotor and connected directly to the trolley.

On 1500 or 1200 volts the motors are connected in two groups, each group having two motors connected in series. Thus the motors are operated all four in series in the first combination, and in two multiple groups of two motors in series in the second combination. On 600 volts the motors in each group are connected in parallel. The motors are then operated in two series groups of two motors in multiple in the first combination, and all four motors in multiple in the second combination.

As a result of these two operating connections, the same voltage is applied to the individual motors when operating on the 600-volt section of the line as on the 1200-volt section. Thus the same running speeds are obtained on both voltages.

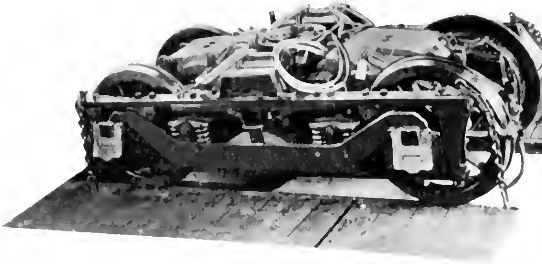

Fig. 2. Side View of Truck with Motors Assembled

The change in connections described is accomplished by means of an air-operated commutating switch. For 600-volt operation this switch changes each two-motor group from the series connection to the multiple connection. It also divides up the accelerating resistance into several sections and reconnects these sections into a number of series groups, each group having two sections in multiple. By this means approximately the same resistance steps are obtained on 600 volts as on 1200 volts.

When transferring from the first motor combination to the second, the transition is accomplished by means of contactors. In transfer; first, part of the accelerating resistance is cut back in circuit; then, one pair of motors is short circuited while the other pair of motors is maintaining torque on the locomotive. Finally, all four motors are connected in two multiple groups with resistance in the circuit. By this method of transfer, torque is never lost in going from the first to the second combination or from the second to the first. It provides smooth operation of the train during transfer and prevents any jolts or damage to draft gear.

Current Collection

The locomotive will operate from an overhead trolley wire. Each is equipped with two pantographs similar to those used on the Chicago, Milwaukee and St. Paul Rwy., the Paulista Rwy., and others. Each trolley has two independent pans with sliding contacts. The contacts are of copper and are easily renewed. The ends of the pans are provided with long horns to prevent fouling the overhead if the pan should run off the trolley wire. The operating range is about 6½ ft., and throughout the range the pressure on the trolley wire is held approximately constant.

The trolleys are air raised and gravity lowered. A hand pump is provided for raising the trolleys when there is no air pressure on the locomotive. This pump may be used either to operate the trolleys directly or to pump air into a trolley reservoir from which air pressure may be obtained later for operating the trolleys. This reservoir may either be pumped up from the hand pump or from the air compressors if the latter are running. A globe valve is connected in the reservoir line which allows air pressure to be maintained in the reservoir for several hours. It will thus rarely be necessary to operate the hand pump.

Main Circuit Switches

The switches in the main motor circuits consist of:

17 electro-pneumatic contactors
1 reverser
1 main switch
1 motor cutout switch
1 commutating switch.

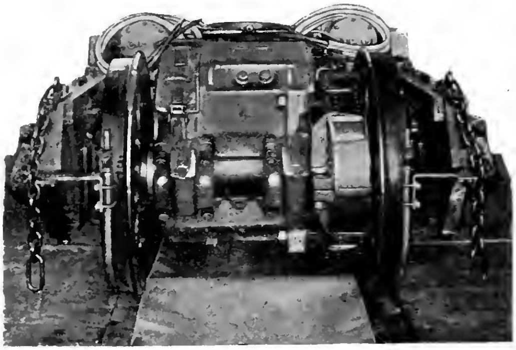

Fig. 3. End View of Truck with Motors Assembled

Contactors

Electro-pneumatic contactors are used to make and break the main motor circuits, to transfer the motor connections when passing from one motor combination to another, and to short circuit the starting resistors when accelerating. Figs. 5 and 6 illustrate this contactor.

It will be seen that the elements of the contactor are mounted on an upright insulated rod. This rod is fastened at the top and bottom to angle-irons in the locomotive by means of U-bolts. This method of support gives considerable flexibility in mounting the contactors in the locomotive. The operating mechanism of the contactor consists of a magnetically controlled air cylinder which operates a piston and rod that in turn operates the movable contact through an insulator. Both contact tips are alike and are cut from a rolled copper section. The contactor has a narrow arc chute with arc suppressor plates which together with the blowout coil give a very effective blowout.

The construction of the contactor with the electro-pneumatic operating mechanism, together with the narrow arc chute and method of mounting, results in a very compact unit which is comparatively light in weight and requires considerably less room for mounting than previous types of contactors of the same capacity.

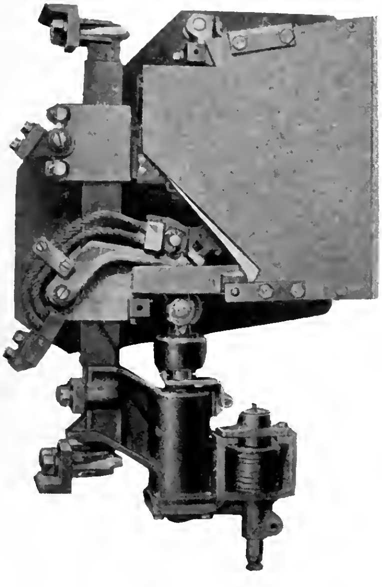

Fig. 5. Electro-Pneumatic Contactor

Reverser

A four-motor electro-pneumatically operated reverser is provided for reversing the traction motors. This device is of a new design that is quite simple in construction. It consists of a series of cylindrical castings which are mounted along an insulated shaft, this shaft being operated by the air cylinders. The contacts are made by fingers mounted on insulated rods on each side of the main shaft. This construction gives a line of reversers for different numbers of motors and of different capacities which have many parts in common.

Fig. 4. Master Controller with Cover Removed

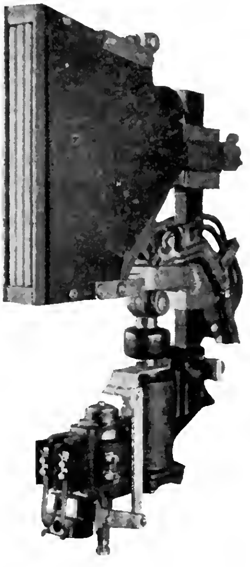

Fig. 6. Electro-Pneumatic Contactor with Interlock

Main Switch

A hand-operated knife-blade switch is placed in the circuit ahead of the main motor equipment. It carries the entire traction motor current and is used to isolate the main part of the equipment when it is desired to test out the control auxiliary circuits, etc.

This switch is mounted on an insulated rod similar to those used for the contactors, and can be mounted if desired on the same angle-iron supports as the contactors.

Motor Cutout Switch

A hand-operated motor-cutout switch is provided for cutting out one pair of motors in case one of the motors is damaged. The locomotive can then be operated by the two remaining motors, either in single unit or in multiple with another locomotive. This switch is very simple in construction and consists of a single-pole double-throw knife-blade switch mounted on an insulated rod similar to those used for the contactors and main switch. The switch carries a number of finger type interlocks which commutate the control circuits for operation with motors cut out. It is mounted on the same angle-iron supports as the contactors.

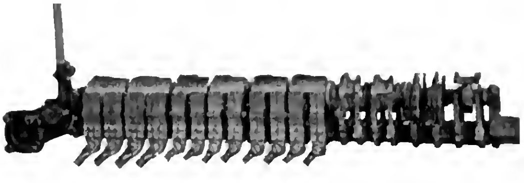
Fig. 7. Pneumatic Commutating Switch

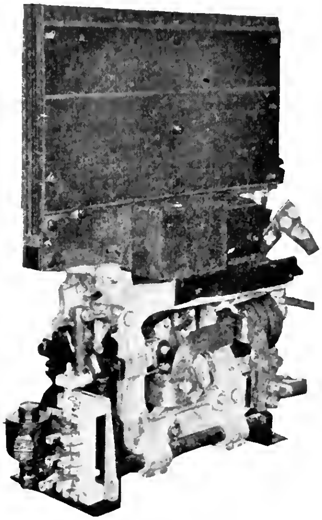
Fig. 8. High-speed Circuit Breaker

Commutating Switch

A commutating switch is provided to change the motor, resistance, and auxiliary circuit connections so that full-speed operation may be obtained on half the normal operating voltage. This switch is air-operated and controlled by hand-operated valves. It is quite similar in construction to the reverser, some of the parts being interchangeable.

The switch, Fig. 7, has contacts for changing the connections of each two-motor group and for dividing up and paralleling the accelerating resistance for operation on low voltage. There are also auxiliary contacts to commutate the compressor and blower connections to run at full speed on half voltage and to change the control voltage connection from the mid-point of the dynamotor to the trolley circuit.

Protective Apparatus

The protective apparatus for these locomotives consists of the following:

1 high-speed circuit breaker
1 overload relay
1 protective relay
1 lightning arrester
Fuses for auxiliary and control circuits.

High-speed Circuit Breaker

Short circuit and overload protection is obtained by a high-speed circuit breaker, Figs. 8 and 9, which is connected in the main motor circuit directly after the main switch. This is a new form of high-speed circuit breaker for locomotive service. It has several features which make it a distinct improvement over those which have hitherto been applied to electric locomotive service.

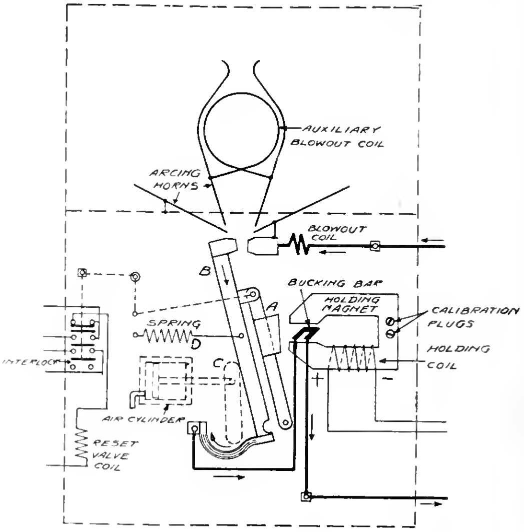

Fig. 9. High-speed Circuit Breaker Connections

In the first place the size and weight for a given capacity have been greatly reduced. It operates on the same principle as those which have previously been described in this magazine;* viz., the armature, operating the movable contact, is held in the closed position magnetically against the tension of strong springs and is released under short circuit or overload by the shifting of the magnetic flux in the holding circuit, due to the action of a bucking bar which carries the entire traction motor current.

Former locomotive high-speed circuit breakers have been closed by a magnetically operated mechanism. This circuit breaker is closed by an electro-pneumatically operated mechanism. Furthermore, the closing mechanism has a trip-free feature. This is obtained by making the movable contact arm separate from the armature and pivoting it from the armature arm. Thus in closing, referring to Fig. 9, the air-operated closing lever *C* pushes the armature *A* against the holding magnet which then holds the armature in against the tension of two strong springs. The closing lever, while closing the armature, at the same time holds the movable contact *B* open. When the air closing mechanism is released, it in turn releases the contact arm, allowing the contact to close by means of the tension of the springs *D*. With this trip-free feature, if the contacts should close on a short circuit, they would open immediately and would not be required to wait until the closing mechanism was released as the contacts cannot close until the closing mechanism starts to drop back. This is a very important advance in high-speed circuit breaker design.

Fig. 10. Overload Relay

As in former circuit breakers this one has a strong magnetic blowout with a narrow arc chute which will effectively open very heavy short-circuit currents.

The tripping point of the circuit breaker is set at the desired value by means of adjustable plugs in the magnetic circuit.

When the circuit breaker opens on short circuit or overload, interlocks open the line contactors. These contactors cannot then be reclosed until the circuit breaker has been reset, which is done on the first point of the master controller.

Fig. 11. Protective Relay

Overload Relay

An overload relay is provided for overload protection of the individual motor circuits. This relay, Fig. 10, has two series coils either of which will operate the relay contacts. One coil is connected in each two-motor circuit. When the motor current exceeds the setting of the relay, the relay contacts are opened against the compression of the resetting springs. This opens the holding circuit of the high-speed circuit breaker, thus causing it to drop out. Operation cannot then be resumed until the master controller has been turned back to the first notch. The relay contacts automatically reset as soon as the overload current is removed.

Protective Relay

When operating from the 600-volt section of the line with the main and auxiliary circuits in the low-voltage connection, protection is afforded in case the locomotive runs onto the 1500 or 1200-volt section of the line and the operator fails to throw the commutating switch to the high-voltage connection. In this event the high-speed circuit breaker protects the main part of the equipment while a protective relay protects the auxiliary circuits. This relay, Fig. 11, is placed in circuit ahead of all the auxiliaries. It has two coils, an

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* "New Type of High-speed Circuit Breaker," by J. F. Tritle, GENERAL ELECTRIC REVIEW, April, 1920.

operating coil and a trip coil, and one set of contacts. The contact arm and the operating armature are independently pivoted but are connected together by a trip catch so that normally the relay operates simply as a shunt contactor, closing when voltage is applied and opening when voltage is removed. In the high-voltage connection the trip coil is not connected in circuit. In the low-voltage connection the trip coil is connected in series with the operating coil and is calibrated to trip out the trip catch at about 700 volts.

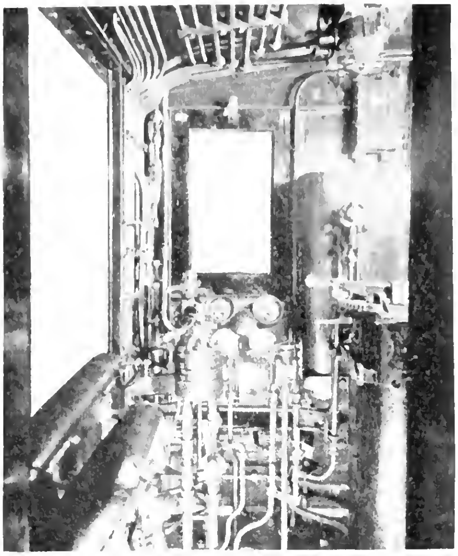

Fig. 12. Operator's Position Showing Master Controller, Air Valves, Gauges, etc.

The following sequence of operations results if the locomotive passes from the low-voltage to the high-voltage section of the line and the commutating switch is not thrown to the high-voltage position. First, the relay contacts open when the dead section of the line is reached. Then, when the high-voltage section is reached, the trip coil operates, tripping out the trip catch and preventing the contacts from closing when the operating coil picks up its armature. A small relay is used to short circuit the operating coil in the de-energized position. This slows up the operating coil and allows the trip coil to operate first.

This scheme gives a very effective protection for the auxiliary circuits as the high potential cannot be applied even momentarily to the auxiliary circuits until the commutating switch has been thrown to the high-potential connection.

Fuses

A cartridge fuse is placed in circuit ahead of all the auxiliaries including the protective relay. The individual auxiliary motors, the control circuits, lights, etc., are protected by cartridge fuses in the auxiliary switches.

Lightning Arrester

Protection from damage by lightning is secured by means of an aluminum-cell lightning arrester especially designed for railway service. This arrester is connected to the trolley circuit ahead of all the apparatus.

Auxiliaries

The control voltage on 1500 or 1200-volt operation is obtained from a dynamotor with a 2:1 voltage range.

Compressed air for the air brakes and pneumatic control apparatus is obtained from two 750-volt air compressors each having a capacity of 35 cu. ft. per min. On 1500 or 1200 volts the two compressors are connected in series, and the lead connecting the compressors is connected to the midpoint of the dynamotor. This balances the load between the two compressors and also provides a means of cutting out one compressor and

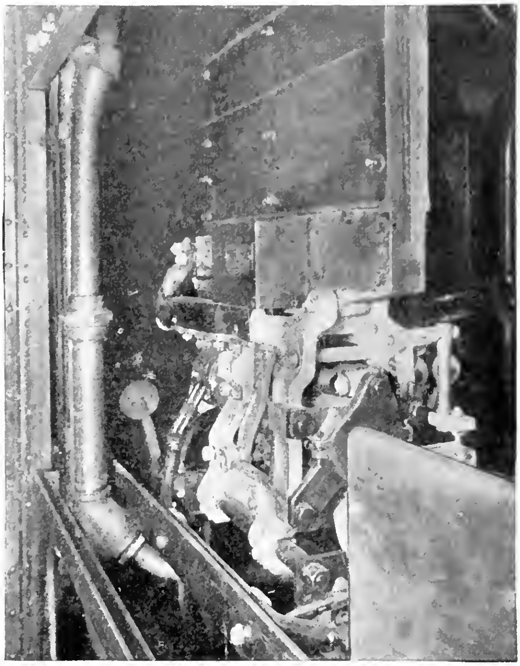

Fig. 13. Apparatus Compartment Showing Location of High-speed Circuit Breaker

operating with the remaining compressor in case of emergency.

On low-voltage operation the compressors are each connected directly across the line thus obtaining full-speed operation on half voltage.

Forced ventilation for the traction motors s provided by two blowers, one for each pair of motors. These blowers are driven by 750-volt motors which are connected in series for 1500 or 1200-volt operation and in parallel on 600 volts

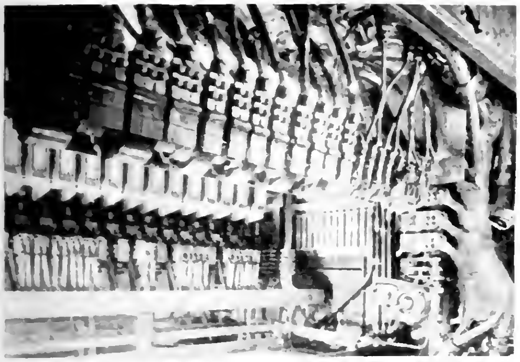

Fig. 14. Apparatus Compartment Showing Location of Contactors, Cutout Switch, Commutating Switch, Reverser, and Resistance Tubes

Location of Apparatus

An idea of the location of the apparatus in the locomotive cab may be obtained from Figs. 12 to 15. The cab is of the box type with the apparatus compartments in the center of he locomotive and an operating cab at either end.

A master controller is located on the left side of each operating cab and is constructed for operation by the right hand. Directly before the operator is a gauge panel containing an. ammeter, voltmeter, and air gauges. In one cab is a mercury watthour-meter for measuring the power input to the locomotive. Each operating cab also contains enclosed hand-operated switches for the auxiliary, control, and light circuits.

There is an aisle connecting the two operating cabs on either side of the apparatus compartments. In the center of the apparatus cab is a compartment containing the accelerating resistors. This compartment extends from the floor to the roof. The air for ventilating the resistors enters through openings in the bottom of the compartment and is vented through a ventilator in the roof. On either side of the resistor compartment is a compartment for the control and auxiliary equipment.

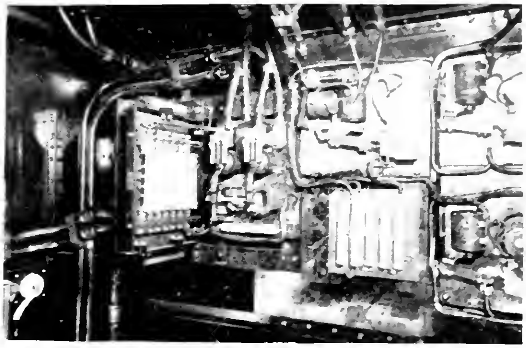

Fig. 15. Apparatus Compartment Showing Location of Relays and Resistance Tubes

The dynamotor, compressors, and blowers are located on the cab floor. The high-speed circuit breaker, contactors, switches, relays, control resistance tubes, etc., are mounted above the motor-operated auxiliaries. This arrangement places the control equipment in a convenient position for inspection or repairs.

From the foregoing description, it may be seen that the principal features of the control equipment for these locomotives are: reduced space occupied, reduced weight, accessibility of parts, and general simplicity.

30-kilowatt 15,000-volt Rectifier for the United States Navy

By A. Schmidt, Jr.

Radio Engineering Department, General Electric Company

In an article on "High-voltage Thermionic Rectifiers" in our February, 1923, issue, the author indicated the remarkable development of the pliotron or vacuum tube converter, with the accompanying demand for power sources up to 15,000 volts direct current to operate these tubes, and then he described the various forms of this type of rectifier. In the following article he describes a specific rectifier of that character developed for the Radio Service of the Navy Department to deliver 30 kilowatts at 15,000 volts with a ripple of not more than one-tenth of one per cent.—Editor.

The 30-kw. vacuum-tube rectifier recently built for the Radio Service of the Navy Department receives three-phase power at 25 cycles, and delivers two amperes at 7000 to 15,000 volts. The rectifier chosen was of the polyphase type with two Y's 180 deg. out of phase and paralleled with an interphase transformer. Variation of the direct-current voltage was secured by tapping the low-tension winding of the transformer. A total of nine taps was needed to supply the necessary voltage range. Twelve kenotrons (UV-218) were used, two being required in each of the six phases to carry the current. The resultant 150-cycle ripple is attenuated in a double-mesh filter having a single tuned element, so that the amplitude of the alternating-current voltage wave in the output is 0.09 of one per cent of the direct-current voltage. A schematic diagram of connections is shown in Fig. 1.

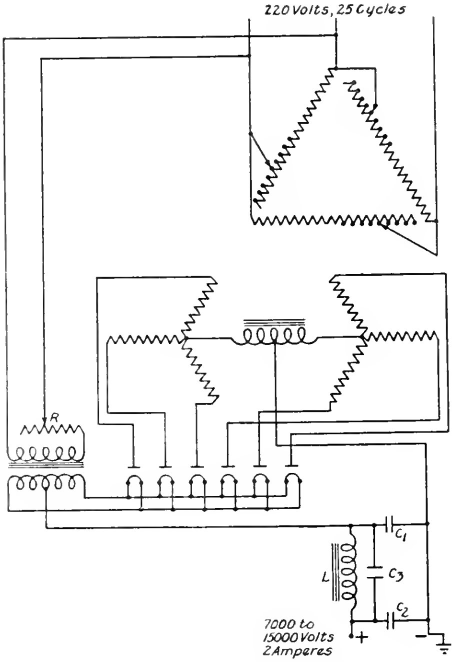

Fig. 1. Schematic Circuit Diagram of the 30-kw. Rectifier

The filaments are lighted from a 220/12-volt transformer, having its low-tension winding insulated for the direct-current voltage to ground. The resistance R regulates the filament temperature. This must be held fairly constant; a material increase in temperature greatly shortens the filament life, while a decrease in temperature increases the space charge loss in the kenotrons. Protective devices are included so that if the temperature should exceed a certain value the set will be shut down, while if it should decrease below a certain value the operator will be warned by an annunciator.

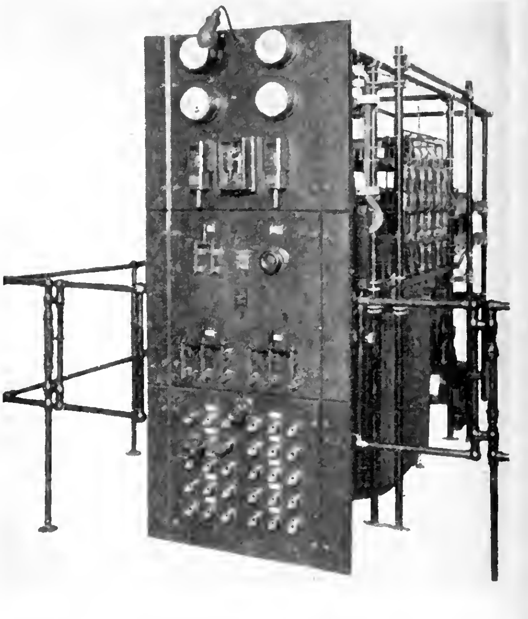

Fig. 2. Front View of the Rectifier showing Panel and Controls

The plate transformer has a rating of 45 kv-a., the primary winding being designed for 40 kv-a. and the secondary winding for 50 kv-a. The higher secondary rating is necessitated by the fact that the secondary current contains a direct-current component which does not appear in the primary. The primary winding is designed to have two parallel sections per phase. Its rating of 40 kv-a. allows for circulating even harmonics in these sections. The transformer draws about 36 kv-a. from the line.

Since there are six phases supplying the kenotrons, the resultant ripple will have a frequency six times that of the supply, and will have an amplitude equal to 5.7 per cent of the direct-current voltage. This ripple is reduced by a double-mesh filter, the first mesh being composed of the leakage inductance of the plate and interphase transformer and the capacity C_1, the second mesh being composed of the capacity C_2 and a reactor L, which has an inductance of 12 henries, tuned to 150 cycles by the capacity C_3. The condensers C_1 and C_2 are of the paper dielectric type.

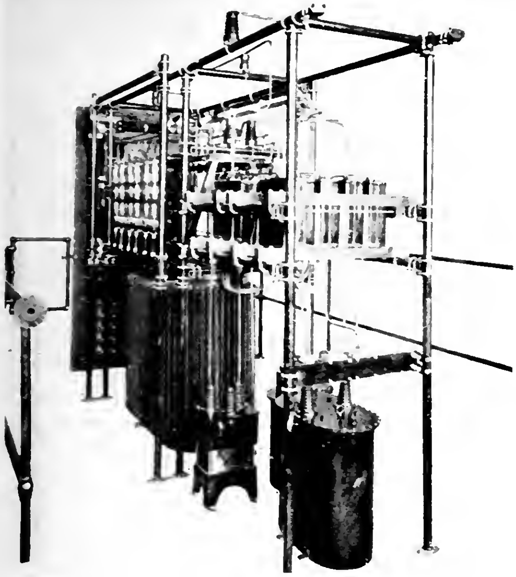

Fig. 3. Rear View of the Rectifier showing Filter and Reactor

Fig. 2 shows a front view of the rectifier. The meters are a line voltmeter, line wattmeter, filament voltmeter, and direct-current ammeter. Below the meters, in the center of the panel, is a relay which protects against changes in filament voltage. If the filament voltage drops to a point where the tubes are likely to overheat, a pair of contacts closes and sounds an annunciator which warns the operator. If the filament voltage becomes excessively high, a second pair of contacts operates on a contactor to shut down the set. On each side of this relay is an overload relay in the main line. Below the relays are switches in the major circuits and a rheostat for adjusting the filament voltage.

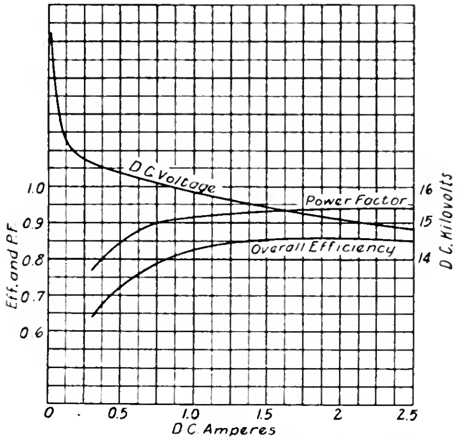

Fig. 4. Performance Curves of the 30-kw. Rectifier on the 15,000-volt Tap

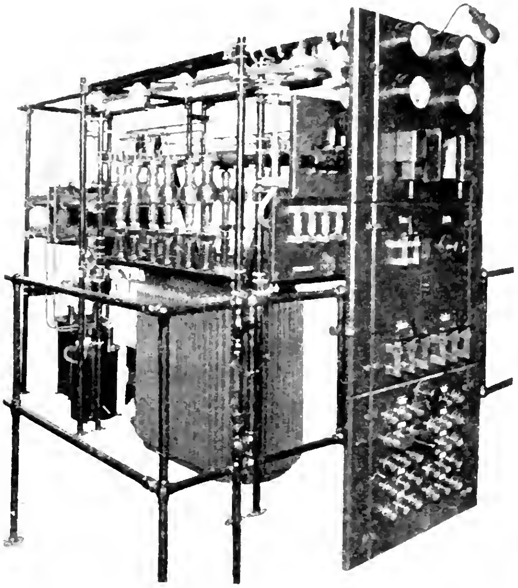

Fig. 5. Side View of the Rectifier showing Transformers and Kenotrons

The taps on the plate transformer are brought out to a set of sockets in the base of the panel. The connection to any tap is closed by means of a three-point plug. A mechanical interlock is provided so that the operator cannot pull out the plug to change taps while the power is on. The rectifier is stopped and started by two push buttons shown in the center of the panel. These operate on a contactor in the main line.

Fig. 3 shows a rear view of the rectifier. The 12 kenotrons are mounted over the plate transformer, six on each side. The smoothing reactor appears in the foreground with its tuning condensers just above it. At the left of the filament transformer is the interphase transformer. The smoothing condensers are mounted in racks above the reactor.

A side view of the rectifier is shown in Fig. 5. A protective switch is provided in each gate so that the opening of either gate shuts down the set. The set cannot be started again until the gate is closed and the start button is pushed.

The performance curves of the rectifier are illustrated in Fig. 4.

Charles A. Coffin Foundation

By W. W. Trench

Assistant Secretary, General Electric Company

In our January issue we made the original announcement of the Coffin Foundation. Mr. Trench, recently appointed Secretary of the Charles A. Coffin Foundation, now tells more about the intent of the awards and gives further details concerning certain phases of the Foundation.—Editor.

The Schenectady newspapers recently told the story of a man who had lately been awarded the Distinguished Service Cross for service performed by him while in the front line trenches during the World War. He crawled out under fire into No Man's Land and brought to the safety of the American lines a wounded corporal. While performing this arduous and brave task, he was desperately wounded. Nothing is so fitting as a reward for courageous acts of this character, where men go outside their line of duty in order to perform deeds requiring conspicuous courage and fortitude.

The world has never shown quite the same interest in rewards for exceptional devotion to duty in the non-military walks of life, even though there exist such notable prizes as the Nobel Peace Prize and the Carnegie Medals. It is, therefore, of more than ordinary interest that the General Electric Company has created the Charles A. Coffin Foundation for this very purpose—To reward special achievements which are outside the ordinary line of duty of men and institutions in the electrical industry. The Charles A. Coffin Foundation establishes a monument, living and vital, in honor of the achievements of a man who, during his life, has been and is today above all things a dynamic, vital leader of men.

Mr. Charles A. Coffin who recently retired as Chairman of the Board of Directors of the General Electric Company is himself a wonderful example of a Distinguished Service man, performing his feats in the walks of industry and finance. No problem has seemed too complex for him to solve, no wall of opposition too mighty for him to surmount; and in overcoming difficulties at every turn, he has found it necessary, in order to promote progress, to do far more than what is ordinarily required of a business man.

It is noticeable that the first provision is for the distribution of the income of the Charles A. Coffin Foundation to employees who make the most signal contributions toward the increase of efficiency or progress in the electrical art. The whole spirit pervading the Foundation is this spirit of progress brought about by exceptional efforts outside the line of duty.

As is the case with all prizes where a few men are picked from a large group for special awards, the administration of the Charles A. Coffin Foundation presents many difficulties. There are many men and women in an organization of over 70,000, such as the General Electric Company, who are from day to day and from week to week performing extraordinary deeds and making startling inventions or suggestions resulting in the increase of the Company's efficiency and the progress of electrical art. One has only to mention a single instance of exceptional service in one department, to have the manager of another department call to mind many parallel instances. Every year the men in the shops of the Company make suggestions for improvement in design of machines and methods of operation, which result in marked progress in the manufacture and greater satisfaction to users of electrical apparatus.

It will be no easy task at the end of this year to choose, from among the best of these suggestions, the winner of the special award of a certificate from the Charles A. Coffin Foundation, but there is every reason that the effort should be made to find the men who have made the outstanding achievements and properly honor them.

The first award under the Charles A. Coffin Foundation will not be made among the employees of the General Electric Company. In June, at the annual convention of the National Electric Light Association, the Charles A. Coffin Medal will be presented to the light and power company in this country which has made distinguished contribution to the development of electric light and power for the convenience of the public and the benefit of the industry.

Intense interest has been shown by leaders in the central station industry in this award and especially in the statement of the factors, which the Committee has announced will be given special consideration. Mr. Frank W. Smith, Chairman of the Charles A. Coffin Prize Committee of the National Electric Light Association, in his interesting letter to the presidents of America's light and power companies, stated that: "Among the factors which will be considered in making the award are the following: The particular initiative, skill and enterprise which have been manifested in popularizing the general use of electrical energy; accomplishments in the development of the efficiency of generation and distribution; the adoption of special plans which have resulted in the largest percentage of increase in new customers; methods adopted of interesting customers in stock ownership; unusual efforts and accomplishments in popularizing and introducing domestic appliances; the extension of service to homes not previously wired and to rural communities."

The Committee has no intention of comparing the standing of various companies but will make its awards purely on the merits of the company's contribution to the progress of the industry.

The real contribution to the electrical industry in the making of the award will undoubtedly come through the emphasis placed by the Foundation on the characteristics of the service rendered by a winning public utility company, which made that company an outstanding leader in the industry.

A similar contribution will be made through competition among the electric railways of the United States for the Charles A. Coffin Medal in the field of electric transportation. What are the accomplishments which should place an electric transportation company in line for this distinguished service award? The Charles A. Coffin Prize Committee of the American Electric Railway Association, which will decide on the winner of this second medal, has attempted to answer this question in a communication addressed by Mr. C. D. Emmons to electric railway companies within our borders. He states that he and his associates will give special consideration to the following factors:

(1) The particular initiative, skill and enterprise manifested in popularizing electric railway service—more riders and more revenue.
(2) Outstanding success in gaining public good-will.
(3) Economies which have been introduced in operation resulting from original ideas.
(4) Economies in operation viewed as a measure of the extent to which the Company has taken advantage of new developments in operating and maintenance practice and equipment, originating with others.
(5) Improvements in construction practice which have resulted in reduced first cost, reduced maintenance, or greater reliability of service.
(6) Particular success in conducting a safety program and actually reducing the number and seriousness of accidents.
(7) Outstanding accomplishment in development of good relations between management and employees.
(8) Special accomplishment, aside from good management, tending to reduce the cost of new capital.

The encouragement which Mr. Coffin has always given to men engaged in research work has been fittingly remembered by including in the Foundation a provision for a group of Fellowships which will be given to young men desiring to continue research work in the fields of electricity, physics, or physical chemistry. The lure of an immediate paying job to seniors in our colleges and universities takes many a man of great powers in the sphere of research forever out of the realm of research. The Committee of distinguished scientists and educators which is to grant the Fellowships hopes that the Charles A. Coffin Fellowships may save to science in the coming years many valuable men. They feel that even if only one man of outstanding ability in research work is placed where he can do his best work without worry concerning finances, the Foundation will have more than justified its existence.

Studies in the Projection of Light

PART IV

CHARACTERISTIC OF A PARABOLIC MIRROR AND SPHERICAL SOURCE OF LIGHT (Cont'd)

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

This installment of the series continues the subject of Part III in which the characteristic formation of the beam was discussed with reference to the increase of central intensity with distance, the inverse-square region, the testing distance for central intensity, and the width of the crest of the beam. The following discussion includes the width of the beam, the testing distance for width of the beam, the movement of the source, a graphical method for obtaining the characteristics of the beam, and gives two examples of the computation of beam characteristics. Particular attention is called to the charts shown as Figs. 32, 33 and 36 which are very useful in determining the limitations, accuracy, and correction factors for any particular photometric beam test.—Editor.

Width of Beam

The edge of a searchlight beam is never sharply and definitely outlined, so that in speaking of the beam width it is necessary to define the term "width." As ordinarily constructed a searchlight (or any of its diminutives, the floodlights) has a field of low illumination nearly 180 degrees wide, and it is essential to fix upon some method of distinguishing between the stray light and the beam proper. It is true that with many searchlights, particularly those having carbon arcs, the edge of the beam seen in the air may be sharply defined to the eye, but if we make an attempt actually to measure the beam diameter, say by throwing the beam against a flat target, we find that the sharpness of the edge is largely an illusion. The beam tapers off into the surrounding field of stray light and two observers might have some difficulty in agreeing to within several minutes of arc.

A rule of practice has been adopted by nearly all photometrists, and by use for a number of years has acquired something of the sanctity of age. This rule may be stated: "The width of a projected beam of light is measured between points on a diameter that have an intensity of 10 per cent of the maximum intensity." To this might be added that the diameter is usually but not necessarily horizontal, and that the maximum may or may not be on the axis. This rule sounds rather arbitrary, but experience has shown it to be satisfactory and seldom in serious disagreement with observational data; and, furthermore, in a large number of cases it has been found that beam widths computed from the size of the light source and the mirror dimensions agree with the rule to within the limits of accuracy.

The 10 per cent rule sometimes has the effect of penalizing a searchlight that is kept in sharp focus, and assigning to it a lower light output than would be given with the same searchlight slightly out of focus. As the beam is thrown out of focus the beam expands slowly, but a relatively large change takes place in the central (maximum) intensity. Ten per cent of the reduced maximum carries the edge out farther than the actual spread, and the additional flux so gained is often a large fraction of the original beam light.

A second "width" is the computed width at a great distance, using either an actual light source or our substitute, the sphere. This is the real maximum beam width and is not to be confused with a spurious maximum obtained at short distance. The third "width" is this width at short range. This latter condition applies to nearly all test conditions, and is therefore of more importance than the limiting width at infinity. This region at comparatively short range which is often, in floodlights particularly, the region of both test and service has some interesting characteristics which will repay investigation.

One of the most confusing features in the discussion of a projected beam of light arises from the inversion that takes place after the light leaves the mirror. The outer rays which form the edge of the beam for some distance from the reflector come from the edge of the reflector, but soon other rays from interior points on the mirror come to the edge of the beam, only to be superseded by light from still more central points, until at infinity the edge rays are from the exact center. It thus happens that the center of the beam at short range is made up in part of the light that will ultimately be the edge rays, and the edge light close to the mirror becomes the center of the beam at great distances. It is because we are often compelled to test at distances where the final rearrangement of rays is incompletely carried out that attention must be paid to this region of crossing rays. If the searchlight was always to be used at the test range, or if the test could always be made at the working range, there would be little occasion to find the relation between various cross sections of the beam. But different photometric laboratories test at different ranges, and the same unit may be used at ranges varying from 25 to 1000 ft.

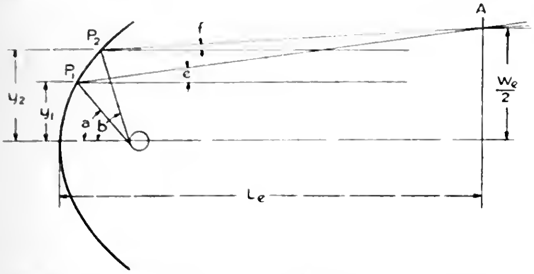

Fig. 28. Crossing Point of Two Rays in a Meridian Plane

Take some point on the mirror, such as P_1 in Fig. 28, and trace the outer ray to some distance L_e, where the distance from the axis is

$$\frac{W_e}{2}=y_1+L_e\tan e \qquad (55)$$

where y_1 is the radius of P_1 and e is the angle between the outer ray and the axis. Also, for any other point P_2 we can write

$$\frac{W_e}{2}=y_2+L_e\tan f \qquad (56)$$

if we assume that the rays cross at some real point in the beam.

Equating (55) and (56)

$$y_1+L_e\tan e=y_2+L_e\tan f$$

$$L=\frac{y_2-y_1}{\tan e-\tan f} \qquad (57)$$

A solution of equation (57) will give the distance to the crossing point of any two rays we choose. If we select two points P_1 and P_2 sufficiently close together then the tangents to the spherical source coincide and the intersection of the two rays becomes the image of the common point of tangency. It is permissible to assume that in certain cases at least these image points will be in the absolute boundaries of the beam, originating as they do from the boundaries of the light source.

We have

$$y_1=2F\tan\frac{a}{2} \qquad (58)$$

$$dy_1=F\sec^2\frac{a}{2}\,da \qquad (59)$$

$$\tan e=\frac{r}{p_1}$$

$$=\frac{r}{F}\cos^2\frac{a}{2} \qquad (60)$$

$$d(\tan e)=-\frac{r}{F}\sin\frac{a}{2}\cos\frac{a}{2}\,da \qquad (61)$$

In the limiting condition when P_1 and P_2 are adjacent points

$$L_e=\frac{dy_1}{d(\tan e)}$$

$$=\frac{F^2}{r\sin\frac{a}{2}\cos^3\frac{a}{2}}\text{ inches} \qquad (62)$$

Equation (62) has been plotted in Fig. 29 for a mirror having a focal length of 7.79 in. and a spherical source with a radius of 0.25 in. The ordinates of the curves were computed from equations (55), (58) and (60), giving

$$\frac{W_e}{2}=2F\tan\frac{a}{2}+L_e\frac{r}{F}\cos^2\frac{a}{2} \qquad (63)$$

The central point on the mirror gives an image at infinity along the straight line through the origin of co-ordinates. It should be noted that the vertical scale of the curves is 20 times the horizontal scale so that the width of the beam is greatly exaggerated. The image points for $a=20$ deg. to $a=60$ deg. are on the upper curve while the image points for $a=60$ deg. to 110 deg. lie on the lower curve as indicated by the plotted dots. As the curve above 60 deg. is within the beam we may call it the imaginary branch. On the left-hand edge of the web two scales are given. One is inches and the other is radii of mirrors having angular openings from 0 to 120 deg. measured from the axis. On account of the compression of the scale in the horizontal direction the curvature of the mirror may be neglected and the mirror surface represented by the straight line used for the base of the stub scale of radii.

A straight line from the radii scale to the same angle on the curve will give the position of the limiting ray from that angle on the mirror. Thus from 60 deg. on the radii scale to 60 deg. on the curve gives the edge of the beam from a 60-deg. mirror of focal length

7.79 in. for the first 750 in., and the upper section of curve gives the remainder of the beam boundary. The beam from a 90-deg. mirror of the same focal length has a straight initial section 790 in. long and from there on the beam edges are identical with the previous mirror. A 120-deg. mirror has first a straight section 1050 in. long and thereafter the beam is identical with the other two. It is to be noted that above 60 deg. there is a sharp turn in the edge of the beam where the initial straight side crosses the upper branch of the curve. Below 60 deg. the straight line is tangent to the boundary curve at the point of contact and the sharp turn is missing.

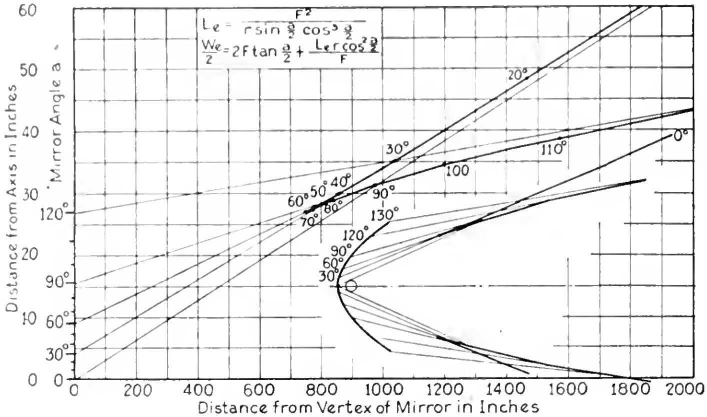

Fig. 29. Boundaries of Beam from a Parabolic Mirror ($F=7.79$ in., $r=0.25$ in. rad.). The outer curves are asymtotic to the beam boundaries at infinity. The inner curves are asymtotic to the boundaries of the inverse-square region

The standard searchlight mirror, which has an opening angle a of 60 deg., gives a beam with but little resemblance to an hourglass, and it will be shown later that in this respect the spherical source differs greatly from the disk source which will be taken to represent an arc crater.

The cusp in the curve of images where the two branches of the curve meet is always formed from the 60-deg. point on the mirror regardless of the value of F or r. The position in space of the cusp does, however, vary with both F and r, increasing in distance L_e from the mirror as the square of F, and inversely as r. It is thus evident that the data points on the real and imaginary branches of the boundary in Fig. 29 can be directly applied only to the particular case for which they were computed.

With the information given by the plot of equations (62) and (63) we are now in position to find how any section of beam differs in angular width from adjoining sections or from the limiting width at infinity.

The half width of the beam from the center of the mirror is

$$\frac{W_0}{2}=L_e\frac{r}{F} \qquad (64)$$

The excess linear width E at any finite distance, expressed as a fraction of the linear width of the beam from the center, is from equations (63) and (64):

$$E=\frac{\frac{W_e}{2}-\frac{W_0}{2}}{\frac{W_0}{2}}=$$

$$\frac{[2\,F\tan\frac{a}{2}+L_e\frac{r}{F}\cos^2\frac{a}{2}-L_e\frac{r}{F}}{L_e\frac{r}{F}}=$$

$$2\sin^2\frac{a}{2}\cos^2\frac{a}{2}-\sin^2\frac{a}{2}$$

or

$$E=\sin^2\frac{a}{2}\cos a \qquad (65)$$

This expression for the excess width shows that the excess is a function of the angle a, but the particular distance L_e and half width $\frac{W_e}{2}$ at which the points lie is also a function of F and r. Thus if it is decided that an error (or correction factor) of one per cent in measurements of beam width is allowable, taking the angular width at infinity as the standard, then we can, by trial, solve equation (65) and find $a=11$ deg. 36 min.; and from equation (62) this excess of one per cent in width occurs at 2430 in. or 202 ft.

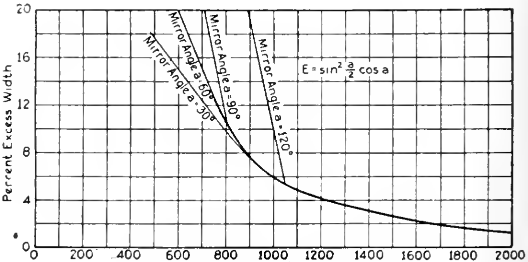

Fig. 30. Excess Width of Beam from a Parabolic Mirror ($F=7.79$ in., $r=0.25$ in. rad.). This width is the excess over the width of the beam from the central part of the mirror

The numerical value of E is positive for all value of a under 90 deg., at which angle the naginary branch of the boundary curve rosses the central beam; and beyond 90 deg. he value is negative, so that without having een the curves of Fig. 29 it would be evident hat not all values of E obtained from quation (65) are real.

The excess widths of beams rom three mirrors of focal length .79 in., having angles of 60, 90, nd 120 deg. are plotted in 'ig. 30. The sharp turn where he straight lines join the comnon curved line marks the juncion of the initial straight ray vith the curved edge of the eam. The sharp upturn at 000 in. shows that only a few eet in that region may take us rom a suitable condition to one hat is not satisfactory for accuate testing.

The imaginary branch of the urve approaches the boundary f the inverse-square region in he same way that the real ranch approaches the outer imiting rays.

'esting Distance for Width of Beam

It has been mentioned that for test purposes t is often better to have the data expressed n terms of beam width rather than in the inear dimensions of the filament. There is a eeming contradiction in this, for it has just been demonstrated that the mathematical xpression for the edge of the beam is rather omplicated, being given in two parts as a unction of the mirror angle, and the exression is discontinuous where the edge ray oins the curved boundary. It will be recalled that the expression for the excess width came out as a very simple function of the mirror angle and this suggests that for testing purposes a chart showing the relation of the measured beam width to the excess width will be the simplest to use.

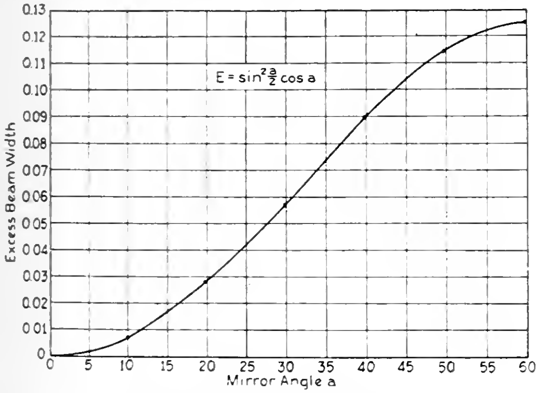

Fig. 31. Excess Beam Width from a Parabolic Mirror as a Function of Mirror Angle *a*

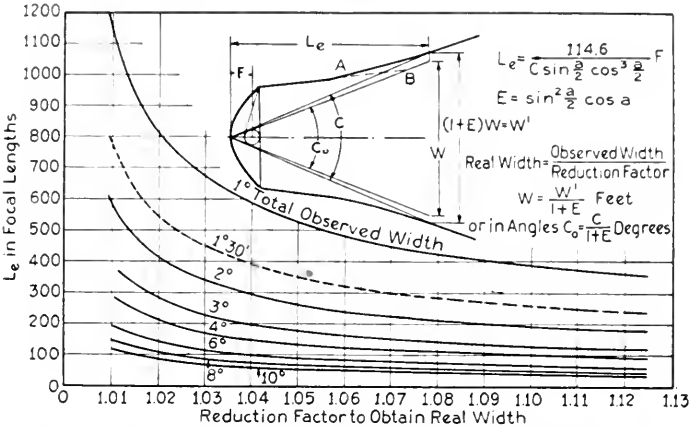

Fig. 32. Charts of Observed and Real Width of Beam from a Parabolic Mirror with a Spherical Light Source

The first step is to replace r and the first power of F in equation (62) by the observed angular width C.

$$L_e=\frac{114.6}{C\sin\frac{a}{2}\cos^3\frac{a}{2}}F \tag{66}$$

This equation used in connection with equation (65) has been used to plot the curves of Fig. 32, where the observed width W', the limiting width W and the excess width E are in the relation

$$W=\frac{W'}{1+E} \tag{67}$$

As an example take a beam of observed angular width of 2 deg. at a test range of 300 times the focal length of the mirror. The chart indicates that the observed width is about 4 per cent greater than the real width and either a greater test distance must be used or the observed width may be reduced by the factor 1.04. If it is desired to have the direct test data correct to within one per cent, the range required is 575 focal lengths; while if an error of ten per cent is not objectionable only 195 focal lengths is required. The latter condition leads to one dangerous possibility and that is the probable existence of an edge ray from the mirror forming the initial straight side of the beam at and beyond the 195 focal-length point.

Equation (57) gave the range L of the crossing point of two rays reflected from the mirror at radii y_1 and y_2. If we make y_1 equal to zero, that is the center of the mirror, and y_2 equal to the radius of the mirror, then the crossing point will be that of the central cone of rays and the outer cone of rays as point *B*, Fig. 32. This is beyond the junction of the outer ray with the curved edge marked *A* in Fig. 32, and therefore point *B* marks a perfectly safe distance for both testing and computing. This point avoids by a considerable margin the sharply upturned branch of the excess-width curves, Fig. 30, that exist for mirrors having an angle *a* greater than 60 deg. It is hardly necessary to consider mirror angles of much less than 60 deg. because of their rarity, and also because their curve of excess width coincides closely with that of the 60-deg. mirror except for distances quite close to the cusp point in the edge curve.

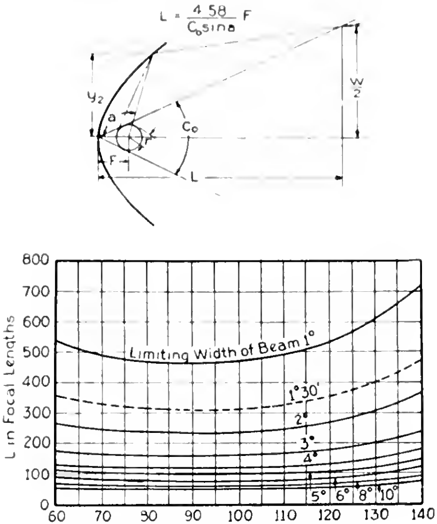

Fig. 33. **Minimum Safe Testing Distance for a Beam from a Parabolic Mirror of Angle *a*. The observed width at this distance may be corrected by the reduction factor given in Fig. 32**

The luminous area of Fig. 25* shows that at a range of 145 ft. the edge of the beam was composed of light from both the center and edge and from an irregular area between. The observed beam width was slightly over 3 deg. and the test range was 220 ft. According to Fig. 32 the observed width was three per cent high. The luminous spot on the left side of Fig. 25* was due to an optical error in the front surface of the mirror which caused it to scatter the five per cent of light reflected from this surface.

Equation (57) transformed to fit these conditions becomes

$$L = \frac{y}{\tan e - \tan f}$$

and using equations (58) and (60) to reduce it further, it becomes

$$L = \frac{4\,F^2}{r \sin a} \qquad (68)$$

Replacing r and the first power of F by the limiting angle C_0 we have

$$L = \frac{458}{C_0 \sin a} F \qquad (69)$$

To use Fig. 33, which is constructed from equation (69), the observed width of beam is first reduced to the real width W (or in degrees C_0) and with this figure the value of L is found from the plotted curves of Fig. 30. If L_e is equal to or greater than L as found from Fig. 33, then the readings on that chart are correct and are not in error through the crossing of an edge ray beyond the test point.

As an example of the use of the two charts in combination, take the case of a mirror of 2.60 in. focal length tested for beam width at 50 ft. radius. The observed beam width is two degrees and the mirror angle is 120 deg. The test distance is 230 focal-lengths and the reduction factor (from Fig. 32) is 1.07. The true beam width is therefore 1.87 deg. Looking up in Fig. 33 a beam width of 1.87 deg. from a 120-deg. mirror we find an indicated test distance of 290 focal-lengths or 63 ft. Therefore the radius of 50 ft. is too

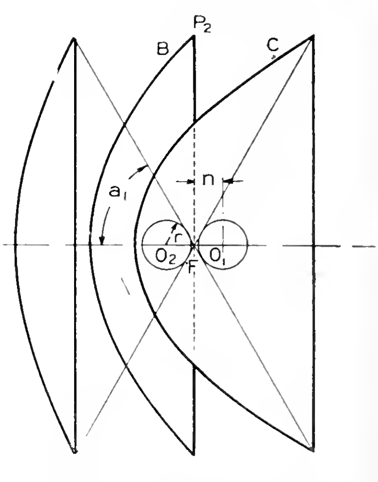

Fig. 34. **Diagram Showing the Maximum Distance a Spherical Source can be Axially Displaced without Diminishing the Central Intensity from Mirror *A*. Under these conditions, Mirrors *B* and *C* reflect light to the center of the beam from only the areas bounded by the angle *a***

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* See Part III of this series, G. E. REVIEW, April, 1923.

ort for measuring the beam width and ther a greater distance should be used, or e width should be carefully investigated in me other way.

Iovement of Source

It is common practice in the use of inandescent floodlights to move the light ource along the axis from the focal point, nd by thus putting the lamp out of focus the eam is broadened, with a corresponding loss central intensity. If the spreading of the ght is carried too far the center of the beam ill become dark. There will always be some ght in the center, but by contrast with the rrounding light it may appear perfectly lack. A beam that stops just short of the lack center is usually soft in outline and free om filament images. Aside from this very ractical feature there is another reason for eing interested in the distribution of light s the lamp is moved. It is possible to move e lamp for some little distance from the act focal position without changing the ntral intensity, and photometric measureents taken on the axis are thus not a good uide for adjusting the lamp.

There is one case in which we may often e justified in establishing the approximate ocal position by means of axial photometric eadings, and that is when testing solely for ntral beam intensity. If the mirror is a fair pproximation to the correct shape, and the esting distance is at least the distance L_0 to e normal inverse-square region, then the aximum reading obtained may be accepted s the true central intensity. The smaller metal eflectors are apt to have zones where the rvature departs markedly from the proper rm, and several of these zones might ncentrate light on a nearby point on the xis but not do it at service distances. herefore, the test distance should be at least qual to L_0, and it seems fair to assume that ny intensity read at that distance can be uplicated at all greater distances.

In Fig. 34 a spherical source is shown moved ther way along the common axis of three irrors of equal diameter. The beam from e 60-deg. mirror with the source at O_2 will aintain its full central intensity at all istances greatly in excess of L_0; that is, at istances great enough so that a small angle f convergence will cause the rays to converge n the axis. This follows because the source onceals the focal point from all points on the irror, and therefore the focal position ppears to be luminous from all points of view. he same is true when the source is at O_1, for then a line may be drawn from the source through the focal point to every part of the mirror. The "freedom of movement" is therefore

$$n = \pm \frac{r}{\sin a} \qquad (70)$$

or 1.15 r for this 60-deg. mirror.

If the mirror extends to 90 deg., the freedom is limited to

$$n = \pm r \qquad (71)$$

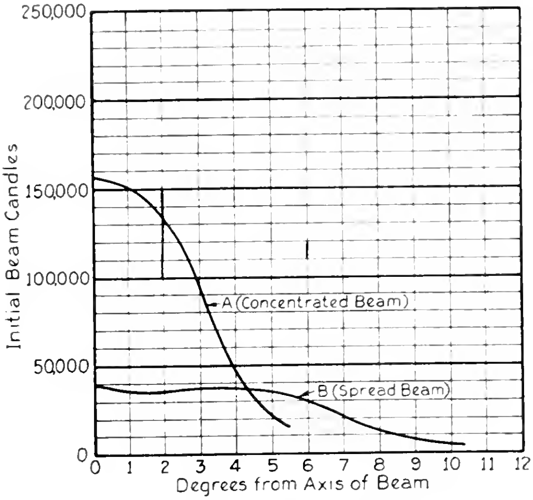

Fig. 35. Curves Showing the Effect of Movement of Light Source on the Spread of the Beam from a Floodlight of Proportions Similar to Those of Mirror *C* in Fig. 34; Curve *A*, with the Light Source at *F*; and Curve *B*, with the Source at O_1

and the same limit holds for all mirror angles greater than 90 deg. One result of the relation shown by equation (70) is that a shallow mirror is easier to focus for maximum central intensity than is a deep mirror. With the source in either position shown in Fig. 34 the 60-deg. mirror will give full beam intensity on the axis, the 90-deg. mirror will give 33 per cent full intensity and the 120-deg. mirror will give only 11 per cent. The active zone for axis illumination is confined to the zone within 60 deg. of the axis, and this zone covers the foregoing percentages of the entire projected mirror area.

The two characteristic curves of Fig. 35 illustrate how the beam intensity changes as the light source is moved away from the mirror. The beam width changed from 11 to 21 deg. while the central intensity dropped to 23 per cent of its original value. The angle of the mirror was nearly 120 deg., the focal length was 3 in., and the radius of the source was about 0.25 in.

When the source is moved along the axis the rays from the outer zone of the mirror are diverged farthest from their normal path, and they may finally become the edge rays for the entire length of the beam. As has been demonstrated the central point of the mirror gives the edge rays at infinity when the source is in focus. As the source is moved either way from the focus, other zones give off the limiting rays and the beam begins to lose its habit of turning inside out between the mirror and infinity.

The edge rays, with the source out of focus, but still on the axis, may be traced with the aid of the method used to derive equation (62). It is first necessary to find how the angle e is influenced by the position of the source. The maximum value of e is not much over ten degrees in any unit that is really projecting light in the ordinary sense of the word. A total beam width of say 30 deg. ($e=15$ deg.) places the unit in the class of indoor lighting fixtures that may be tested and used at short range, and only in special cases can it be treated as a projector. With this limit in mind the mathematics of the out-of-focus beam may be simplified without a serious loss of accuracy. In Fig. 36 the source is shown moved a distance S toward the reflector. The angle e may be approximated by

$$\tan e=\frac{T+r_1}{p} \tag{72}$$

in which equation

$$T=S\sin a \tag{73}$$

$$r_1=r\frac{p+S\cos a}{p} \tag{74}$$

therefore

$$\tan e=\frac{S}{p}\sin a+\frac{r}{p}+\frac{rS}{p^2}\cos a=$$

$$\frac{S}{F}\sin a\cos^2\frac{a}{2}+\frac{r}{F}\cos^2\frac{a}{2}\mp\frac{rS}{F^2}\cos a\cos^4\frac{a}{2} \tag{75}$$

The edge of the beam was seen to be composed of a series of image points formed by adjacent rays in a meridian plane. The method of deriving equation (62) should therefore apply when the source is out of focus.

$$L_e=\frac{dy}{d\,(\tan e)}$$

$$=\frac{F^2\sec^3\frac{a}{2}}{S\cos\frac{3a}{2}+r\sin\frac{a}{2}\pm\frac{rS}{2F}\sin a\cos\frac{a}{2}(1+3\cos a)} \tag{76}$$

As we are interested only in the beam width at great distance, we may write

$$L_e=\text{infinity} \tag{77}$$

which in equation (76) is true only when $a=180$ deg. (which is not a practical limit of mirror construction) or when the denominator is equal to zero.

Therefore, after simplifying by changing several factors from functions of $\frac{a}{2}$ into functions of a and dividing by $\sin a$, we get

$$S=\frac{-r\sin\frac{a}{2}}{\cos\frac{3a}{2}\quad\frac{\mp r}{2F}\sin a\cos\frac{a}{2}(1+3\cos a)} \tag{78}$$

This equation is plotted in Fig. 36 where the focal length was taken as unity and r was made equal to one-tenth, which is about the proportions of the 120-deg. mirror with a half-inch diameter source used in several previous illustrations. The two lower branches show what angle on the mirror gives the ray of maximum divergence for various positions of the light source. The branch to the left is for positions between the focal point and the mirror. Thus the 0.2 focal-length position of the source gives a maximum spread of light from the 50-deg. zone on the mirror. A position 0.2 focal lengths beyond the focal point has a higher zone for the ray of maximum spread.

It will be noted in the illustration that the ray of maximum spread never comes from points beyond 60 deg. on the mirror. This indicated that if the mirror angle is over 60 deg. there is always a curved edge to the beam; whereas if the mirror is say 40 deg. wide (equal to angle a) and this particular source is set either 0.14 focal lengths ahead or 0.22 focal lengths back of the focus the beam edge rays at the mirror edge will continue to be edge rays to infinity.

The two upper curves of Fig. 36 are minimum divergences for rays from the periphery of the light source, and these curves therefore are related to the imaginary branch of the locus of edge points with the beam in focus; they locate the zone that gives the inner rays of the hollow beam. Once the proper mirror zone is determined, the computation of angle e is easily carried out.

It has been found in the actual application of the out-of-focus beam that better results are obtained with the lamp moved away from the mirror. The central part of the mirror concentrates its light a little better into the center of the beam and for equal spreads the center of the beam is stronger. This makes the beam more uniform particularly when it is spread to the point when the center shows signs of becoming dark.

One feature of the spread beam that is of engineering importance is the higher output of a floodlight when the beam is out of focus, even if the lamp is moved away, so that less light falls upon the mirror. Thus in Fig. 35 the in-focus beam contained 1930 lumens and when the lamp was moved forward the beam lumens rose to 2090 lumens. The explanation of this paradox is found in the stray light between 5.5 and 10.5 deg. that was not included in the concentrated beam. The ten per cent rule is evidently involved in this difference between 1930 and 2090 lumens, for with the integration of light carried to the same upper limits for both beams they should reverse their relative efficiencies.

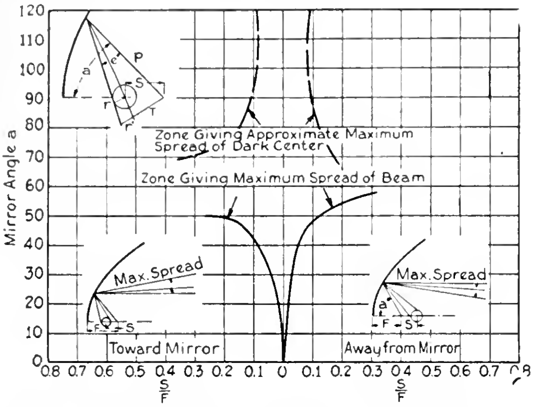

Fig. 36. The Solid Curves Show the Mirror Zones that Give the Maximum Spread of Light from Parabolic Mirror Having a Spherical Source of Radius 0.1, the Mirror Focal Length Displaced Out of Focus Axially. If the center of the beam is dark under these conditions, the dotted curves show the mirror zone that gives the inner boundary of the hollow beam

Another feature of the spread beam is the false value that may be placed on a defective mirror that gains in beam width through surface defects. Unless the added width is kept in mind the mirror may be improperly credited with a higher coefficient than a mirror of good curvature.

A Graphical Method of Obtaining the Beam Characteristics

It will be recalled that of the several features of the beam that have been investigated and charted, only one, the increase of central intensity with distance, has been completely covered. The theory of the edge rays, which is in some ways complete, does not take into account the ten per cent rule used in photometry, and the subject of the inverse-square region was left unfinished with the promise of future attention. Of the region between the inverse-square region and the edge, the theories so far developed say nothing. The good and sufficient reason for this omission is that this intermediate region cannot be investigated by considering only what happens in a meridian plane, but we must have recourse to solid geometry. The author has started several times to carry out an investigation of this intermediate region, but the mathematical forms encountered at the very beginning left but little hope of an ultimate simplification that would allow an easy application to practice.* The desire for data was prompted by practical needs and a simple solution was therefore desired.

As contrasted to the strictly geometrical solution the optical solution here given is extremely simple and direct, and in its applicability is undoubtedly more general particularly to the special cases of odd shaped sources or defective mirrors.

The image formed by a parabolic mirror is at infinity, but as has been pointed out the image is rather a multiplicity of images of various sizes than a simple image that duplicates the outline of the source. We can build up the composite image by dividing the mirror into a number of concentric zones and then determining separately the image given by each zone. The method is perfectly general and may be applied to any source in focus or out of focus. A summation of the images gives the beam from the entire mirror area. There are only a few equations needed. One is the equation for the plane area of the zones:

$$A = 4\pi F^2\left(\tan^2\frac{n}{2} - \tan^2\frac{m}{2}\right)\text{sq. in.} \quad (79)$$

where F is the focal length in inches,

n is the angle to the outer edge of the zone,

m is the angle to the inner edge of the zone, and

A is the plane or projected area of the zone.

The angular size of the image from the zone is determined by the size of the source (radius $= r$) and the distance p from the focal point to the center of the zone. We may take an average angle:

$$a = \frac{n+m}{2}\text{ deg.} \quad (80)$$

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* The mathematical investigation has been carried out and published by F. Henning, in the *Elektrotechnisch Zeitschrift*, Vol. 41, 49 and 50, Dec. 9 and 16, 1920, pp. 973-976 and 1006-1008. In the illustrations of the theory the difficult middle distance is avoided.

as representing the center of the zone. The angular radius b of the image is then obtained from

$$\tan b = \frac{r}{P}$$

$$= \frac{r \cos^2 \frac{a}{2}}{F} \text{ numeric} \qquad (81)$$

In selecting the zones it is well to keep in mind the progressively increasing size of the zones as the angle a (or n and m) is increased The values in Table II are for 10-deg. zones up to 120 deg. from the axis.

TABLE II

ZONE AREAS AND IMAGE WIDTHS

Unity Focal Length and Spherical Light Source of Radius $r = \frac{F}{100}$

ZONE BOUNDARIES			PROJECTED AREA			IMAGE RADIUS	
From	To	Mid. Zone a	Zone	Total	Radius P	Degrees	Per Cent
0°	10°	6° 40′	0.096	0.096	1.004	0° 34.25′	99.6
10°	20°	15°	0.295	0.391	1.018	0° 33.79′	98.2
20°	30°	25°	0.512	0.903	1.049	0° 32.79′	95.3
30°	40°	35°	0.762	1.665	1.100	0° 31.25′	90.9
40°	50°	45°	1.064	2.729	1.172	0° 29.34′	85.3
50°	60°	55°	1.455	4.184	1.271	0° 27.04′	78.7
60°	70°	65°	1.972	6.156	1.405	0° 24.47′	71.1
70°	80°	75°	2.697	8.853	1.588	0° 31.65′	62.9
80°	90°	85°	3.713	12.566	1.839	0° 18.70′	54.4
90°	100°	95°	5.290	17.856	2.189	0° 15.71′	45.7
100°	110°	105°	7.794	25.650	2.699	0° 12.74′	37.0
110°	120°	115°	12.045	37.695	3.461	0° 9.93′	28.9

These data are plotted in Fig. 37. The width of the beam from the 0 to 10-deg. zone is taken as twice 0 deg. 34.25 min., and the intensity of the beam is plotted as proportional to the area of the zone. This implies a light source of one candle per square inch brilliancy and a mirror of perfect reflectivity. The image from the second zone, 10 to 20 deg., is slightly narrower and about four times as intense. The zone images are plotted one on top of another until the 110- to 120-deg. zone is added. The resultant figure is a pile of rectangles that must be merged into one another, which we may readily do by drawing a smooth curve through the centers of the vertical steps. This smoothing out could be eliminated by taking small steps, say 1-deg. zones on the mirror, but nothing would be gained thereby.

In Fig. 37 heavy lines are drawn across the beam characteristic denoting the tops of beams from a 60-deg. mirror and a 90-deg. mirror of equal focal lengths. When these part beams are compared with the beam from the 120-deg. mirror it will be seen that the outer zones, on account of their greater area, are of prime importance.

If three mirrors of equal radius and variable angular widths, such as 60, 90 and 120 deg., are investigated, it will be found that they give, as plotted in Fig. 38:

(a) Equal central intensities (equal areas)

(b) Widest beam from 60-deg. mirror.

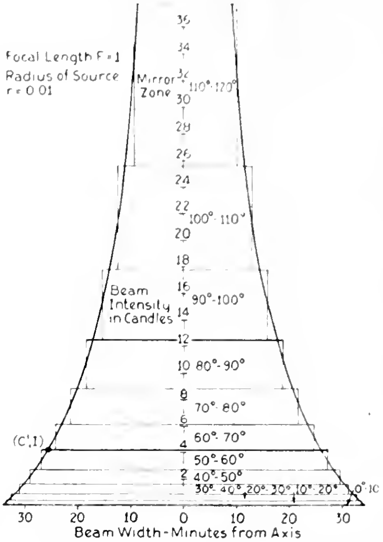

Fig. 37. Synthetic Method of Arriving at the Distribution of Light in a Beam by Adding the Light from the Different Angular Zones of the Mirror

(c) Narrowest beam from 120-deg. mirror.

(d) Narrowest inverse-square region (flat crest) for 90-deg. mirror and

(e) Equal width of inverse-square region for 60- and 120-deg. mirrors.

Computation of Beam Characteristic

Perhaps the first thing to mention in connection with the computation of the beam characteristic is that it applies only to the beam at great distances, and thus gives data that are too often not attainable by test methods. If all tests could be conducted at a range of say 1000 or even 2000 times the focal length of the mirror, then the graphical method just outlined and the geometrical method about to be described would be ideal for checking or even eliminating the actual test work.

This section is placed after the section on a graphical determination of the beam characteristic because the diagrams used to illustrate the methods are the same.

Taking again the mirror with a focal length of unity and a spherical light source of radius 0.01, the angular width of the beam is C degrees; C being obtained from the relation

$$\tan C = \frac{2\,r}{F} \text{ numeric} \qquad (82)$$

or replacing $\tan C$ by the angle C, the half width

$$\frac{C}{2} = \frac{57.28\,r}{F} \text{ degrees} \qquad (83)$$

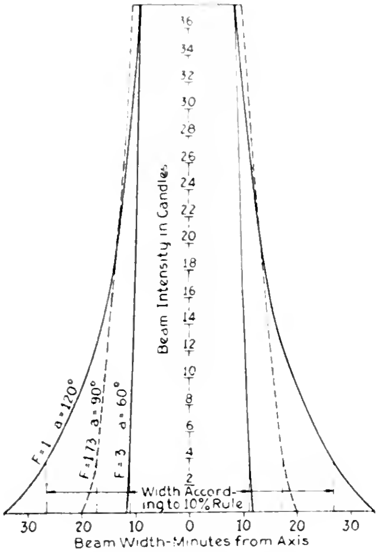

Fig. 38. These Curves, Derived from Fig. 37, Show that Three Mirrors of Equal Diameter and Having Angles *a* Equal to 60, 90 and 120 Deg. Give Beams of Equal Central Intensity but Unequal Width

In Fig. 37 this is the point on the characteristic curve where it crosses the axis at zero intensity. At some other point such as (C', I) at the top of the 50- to 60-deg. image, Fig. 37, the angular half width corresponds to the spread of light reflected from the 60-deg. point on the mirror. The angle varies inversely as the radius vector p, therefore F in equation (83) is replaced by p and

$$\frac{C'}{2} = \frac{57.28\,r}{p} \text{ degrees}$$

$$= \frac{57.28\,r\cos^2\frac{a}{2}}{F} \text{ degrees.} \qquad (84)$$

The summation of images in Fig. 37 is based on the fact that at sufficient distances the luminous area of the mirror grows in concentric rings from the center outward as the observer moves from the edge of the beam toward the center. The luminous area up to a degrees is then

$$A = \pi y^2$$

$$= 4\pi F^2 \tan^2\frac{a}{2} \text{ square inches} \qquad (85)$$

The intensity of light is

$$I = ABk$$

$$= 4\pi\ BF^2k\tan^2\frac{a}{2} \text{ candles} \qquad (86)$$

Equations (85) and (86) give the characteristic curve of beam intensities of a parabolic mirror and a spherical light source. The brilliancy of the source is one candle per square inch and the coefficient of reflection k is taken as unity in Fig. 37.

Testing Distance for Entire Characteristic

Attention is called to the different manners in which L and L_0 vary with the angular proportions of the mirror. In Fig. 22* three beams were sketched for the same spherical source with three mirrors of equal diameter but variable angle a. The 60-deg. mirror requires a "safe" distance L several times L_0; the 90-deg. mirror can be measured for beam width at about one and one-third the distance L_0 necessary for measuring full central intensity; while the beam from the 120-deg. mirror can be measured for width at one-third the distance L_0. It is therefore necessary to investigate each characteristic separately.

The indoor searchlight range of the Illuminating Engineering Laboratory† has a usable length of 150 ft. The measurements of beam flux are made by throwing the beam into a hemispherical photometer 110 in. in diameter. At a distance of 150 ft. the hemisphere subtends an angle of 3 deg. 30 min. Smaller angles are obtained by partially closing the iris shutter with which the instrument is provided, and larger angles are obtained by moving the integrator down the track closer to the projector under test. This test equipment is an excellent example of the physical limitations encountered in photometry, and the application of the formulas and charts so far derived for these conditions will show how the theories apply to practice.

Take the case of a floodlight with a diameter of 16 in. and a focal length of 3 in. The lamp filament (the filament of Fig. 39b) is 0.5 in. in average diameter. This unit is provided with a convex glass door of low optical accuracy.

The computed beam width is 9 deg. 30 min.
The observed beam width is 11 deg. 0 min.

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* See Part III of this Series G.E. REVIEW, April, 1923.

† Information concerning this range and its photometer is given in the article "Some Features of the High-intensity Motion Picture Arc," G.E. REVIEW, Sept., 1922, p. 555.

A low optical accuracy for the unit is indicated by the difference between 9 deg. 30 min. and 11 deg. and we may regard the beam as being 10 deg. wide. This will give us a certain factor of safety because the condition for testing a 10-deg. beam is normally harder to satisfy than that for an 11-deg. beam.

Distance to inverse-square region by equation (45) $L_0 = 22$ ft.

Available distance, 150 ft. $= L = 6.8\ L_0$.

The accuracy of measurement for the width of the inverse-square region is by equation (54) equal to 0.85, which seems ample for a low-accuracy unit.

The integrator is set at 52.7 ft. to measure a beam of 10 deg. observed width. This is 210 focal lengths for this mirror. The curves of Fig. 32 show an accuracy better than one per cent for these conditions, which is more than ample. We may therefore conclude that the dimensions of the indoor range and equipment are sufficient for this unit. If the beam is spread the test conditions are less severe, except for L_0 which increases if the lamp is displaced toward the mirror.

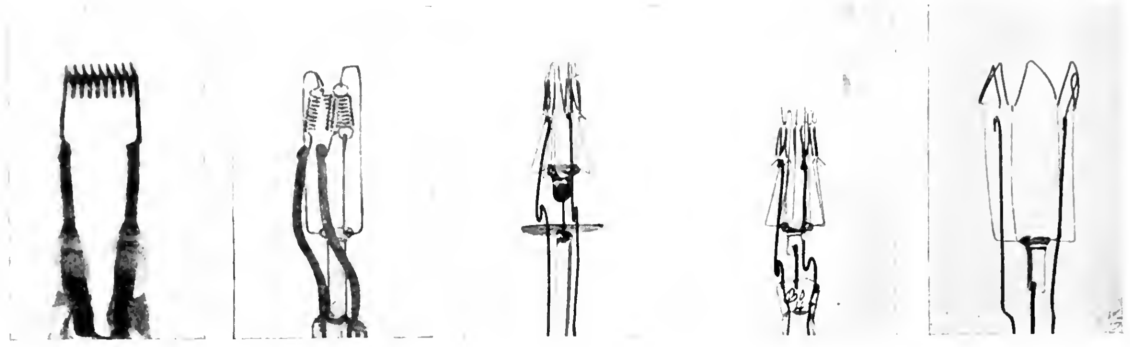
(a) (b) (c) (d) (e)

Fig. 39. Analysis of the Projection Characteristics of Various Type of Filaments

(a) When the axis of the helix of this filament coincides with the axis of the mirror the beam practically duplicates a spherical source beam
(b) This filament gives a beam greatly resembling that from a spherical source
(c) This filament has almost as good characteristics as that in (b)
(d) The concentration of this filament is only slightly inferior to that of (c)
(e) A filament with as great a spread as this is practically useless for projection purposes

As a second example, let us investigate the conditions when an 18-in. high-accuracy mirror of 7.79 in. focal length is equipped with the same lamp and a precision door.

The computed beam width is 3 deg. 41 min.

The observed beam width is 3 deg. 45 min.

An optical accuracy of mirror and door beyond the limits of the test is indicated.

Distance to inverse-square region by equation (45) $L_0 = 31$ ft.

Available distance 150 ft. $= L = 5\ L_0$.

Accuracy of measurement of width of the inverse-square region is 0.80, which is low for this unit.

The integrator is set at 140 ft. to measure a 3-deg. 45-min. beam. This is 216 focal lengths. From Fig. 32 an accuracy of width of about two per cent may be expected, which is satisfactory. From Fig. 33 a 3-deg. 45-min. beam from a 60-deg. mirror required 150 focal lengths hence the distance is beyond the straight edge of the beam.

The above data show the conditions to be ample for the determination of maximum intensity and beam width, but it leaves something to be desired in measurements on the shoulders of the beam characteristic which is in that region that for short ranges remains unexplored.

The Agricultural and Industrial Features of Priest Rapids

THE LARGEST POSSIBLE HYDRO-ELECTRIC DEVELOPMENT IN THE UNITED STATES WEST OF NIAGARA FALLS

By Henry J. Pierce

President, Washington Irrigation and Development Company, 71 Broadway, New York City

The author shows the vast possibilities for increased agricultural and industrial enterprises if the largest hydro-electric project in the West is developed. This single development when completed will make an appreciable difference in our national wealth.—Editor.

The Land

When the pioneers of 1840 travelled toward the Pacific Northwest, some of them remained in the fertile wooded country of Eastern Washington, while others pushed further west and, leaving behind what they deemed a vast useless desert traversed by the Columbia River, crossed the Cascade Mountains and settled in "the American Riviera" lying between the mountains and the ocean.

For the most part, the great Columbia River Valley or, as it is coming to be called, "The Priest Rapids Valley" is in the same primitive condition as when the pioneers crossed it in 1840. Its hundreds of thousands of acres, having but four inches of rain per year, constitute a desert sage brush country, the greater part having a population of less than one person per square mile.

But this vast unproductive area of land, when given water, will become one of the richest agricultural districts in the world. The volcanic ash soil is a veritable treasure in its content of fertilizing material. Given water, it will produce, with its 300 days of sunshine, every crop that can be grown in the temperate zone, such as sugar beets, tobacco, peanuts, soy beans, sweet potatoes, every kind of vegetable, and flax, barley, rye and wheat give wonderfully abundant crops. Corn grows nine feet high. Even Egyptian cotton planted in April comes to full fruition by September. A few green oases already glisten in this desert. Twenty thousand acres planted to apples at Wenatchee yield an annual crop of $10,000,000 or over $500 per acre, but hundreds of thousands of equally fertile, but now thirsty acres remain to be reclaimed from the desert with water from the mighty Columbia which washes their shores. What a marvelous combination! Water, 300 days of sunshine, and in the rushing rapids of the river latent horse power waiting to be harnessed to lift the water to the parched land. Water, land, sunshine and power with resultant crops four times as great as is obtained from lands which are copiously watered by rain.

The Location

As shown by the map on page 292, Priest Rapids is situated almost exactly in the center of the State of Washington. The four principal cities of the Pacific Northwest—Portland, Seattle, Tacoma and Spokane—having an aggregate population of 800,000, are each about 150 miles distant. Priest Rapids is located upon the Chicago, Milwaukee & St. Paul Railroad and with the completion of the projected Wenatchee Southern Railroad will have connection within 60 miles to the North and South with four transcontinental railroads—the Union Pacific, Northern Pacific, Great Northern, and Chicago, Milwaukee & St. Paul.

The River

The Columbia, twelfth largest river in the world, second largest in the United States, carries a greater annual volume of water than the Mississippi at Memphis. Its drainage area above Priest Rapids is estimated at 95,000 square miles. The river is navigable from the Pacific Ocean to the foot of Priest Rapids. With the installation of locks and a dam at Priest Rapids, navigation will be extended for a further distance of 130 miles into the interior of the State of Washington, to within 110 miles of the Canadian Border. The Columbia is now navigable for ocean going vessels for 120 miles from its mouth, and for 1000-ton river steamers and barges from that point to Priest Rapids. Therefore, with one change of bulk, water transportation can be had to and from Priest Rapids and any port of the world.

The Columbia falls 90 feet in nine miles at Priest Rapids. Its flow during the low-water period in the winter averages 50,000 second-feet, and during the summer months sometimes reaches 500,000 second-feet or over twice the flow of the Niagara River at Niagara Falls.

The Water Power

Priest Rapids constitutes the largest possible hydro-electric development in the United States west of Niagara Falls. Its total ultimate capacity is 650,000 h.p., of which 400,000 h.p. is primary power available every day in the year, 100,000 h.p. is secondary power available during the irrigation season from April to October, and 150,000 h.p. is five months' secondary power available from May to September inclusive. The dam will be 90 feet high and two miles long—the largest in the world; longer than the Assouan Dam in Egypt.

Secondary Power

The low-water period west of the Cascade Mountains occurs in the summer, which is the high-water period at Priest Rapids. Therefore, it is proposed to build a transmission line 110 miles long from Priest Rapids to connect with the already inter-connected lines of the power plants located west of the Cascades, which supply electric energy to Seattle, Tacoma and the western portion of the state, and to transmit 150,000 horse power of Priest Rapids secondary power to make up the summer shortage. Sufficient power can be transmitted to Priest Rapids during the winter from west of the Cascades if made necessary by any unusually low-water stage, whereby to stabilize and always keep uniform Priest Rapids 400,000 h.p. primary power. Thus two uses are provided, agricultural and

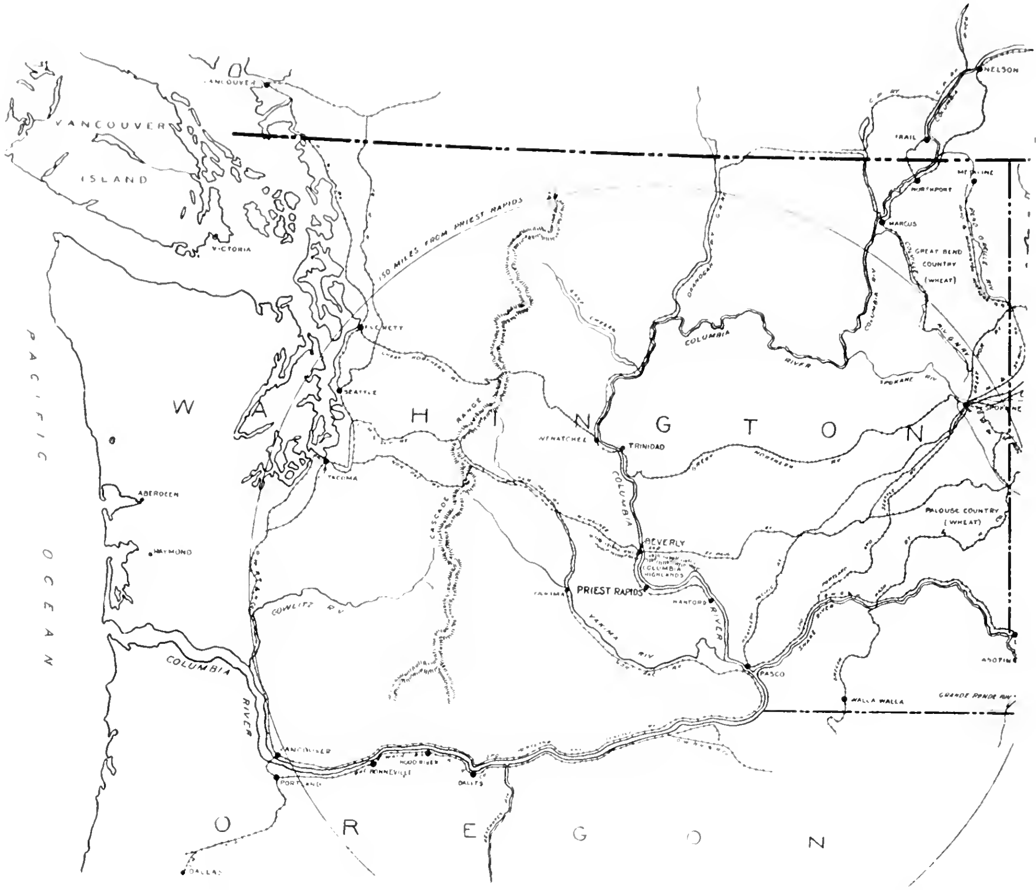

Fig. 1. Map of the Territory Involved in the Priest Rapids Development

transmission, which will absorb all of the 250,000 secondary horse-power to be developed at Priest Rapids. It is most remarkable that this region should itself furnish use for this immense output of secondary power, while not requiring at the outset the primary power.

Primary Power

All the problems in connection with the Priest Rapids hydro-electric project have been solved except finding uses for sufficient of the 400,000 primary horse-power to justify the beginning of construction. The secondary power can be sold for irrigation and transmission purposes. The necessary lands and Federal and State permits have been acquired.

Raw Materials

The owners of the power project own a limestone deposit of which it is estimated there are ten million tons in sight, averaging 98 per cent pure carbonate of lime. They also own 600 acres of high-grade alumina clay which contains 40 per cent alumina and but a small percentage of impurities other than silica. Coal, high-grade iron ore and coke of good metallurgical quality can be delivered at Priest Rapids at a reasonable price. Ninety per cent of the three billion tons of high-grade phosphate rock estimated to exist in the United States is within the states of Idaho, Montana and Wyoming.

Natural gas wells of considerable capacity have been drilled 20 miles from Priest Rapids.

Fig. 2. Foaming Waters of the Columbia River at Whole Chute, Priest Rapids, Washington

The foundations for the dam have been tested and found satisfactory. The engineering plans have been practically completed, and financing has been arranged for. Construction will be begun immediately upon use being found for the primary power. A certain amount of power can be sold for public utility purposes. The railroads will before long undoubtedly require a large amount of the power for electrification of their lines. But industrial use must be found for at least 200,000 h.p. before development will be justified. Those in charge of the project are using every effort to induce the establishment of manufacturing plants at Priest Rapids which will utilize its cheap power for production of basic materials, and it is believed that these efforts will soon be successful.

The following are among the metallic, non-metallic and other substances which exist within 500 miles of Priest Rapids:

Coal
Chromium
Copper
Lead
Manganese
Molybdenum
Gypsum
Kaolin
Silver
Tungsten
Vanadium
Zinc
Leucite
Limestone
Marble
Mica
Phosphate Rock
Pyrites
High-grade Iron Ore
Clay, alumina
Clay, china
Clay, fire
Clay, pottery
Clay, porcelain
Natural Soda
Silica
Sodium Sulphate
Diatomaceous Earth
Feldspar
Fluorspar
Timber products
Alunite

Practically none of the great staples are now being manufactured on the Pacific Coast. The manufacturers who locate at Priest Rapids will have for their export market half the population of the world facing them across the Pacific.

It is hoped that Priest Rapids will be the Niagara Falls of the West, and that its power will be used for a diversity of manufacturing purposes, whether great or small.

Priest Rapids is one of the few great pioneer projects remaining undeveloped in the United States. It will be the second largest hydro-electric plant in the world, and co-incidentally with its construction great industrial plants will be erected to utilize its power when ready; a city of 30,000 people will be built, and vast acreages of nearby land will be brought under cultivation, supporting a large agricultural population. Probably over one hundred million dollars will be expended in connection with bringing the Columbia River Valley to life. The time is near when this tremendous work of co-ordinating the uses and values of water, land, sunshine and water-power will be begun.

Electric Propulsion for the New San Francisco-Oakland Terminal Railway's Ferryboats

By L. Rask

Marine Department, General Electric Company

The author gives a brief but interesting account of the novel features in the equipment of these new ferryboats. Changeable speeds with this arrangement of propellers is an interesting innovation even in ferryboats.—Editor.

The new ferryboat, *Hayward*, that operates between San Francisco and Oakland on the Key System, is the first ferryboat in the world to use steam turbine electric drive, with a Ward Leonard system of control for maneuvering. This boat was recently put into operation, and there is a sister ship, *San Leandro*, that will soon begin to operate on the same route.

These boats are owned by the San Francisco-Oakland Terminal Railways and help to carry the passengers of the Southern Pacific Railroad from the Oakland Terminals over the Bay to San Francisco. The boats also carry their share of the large masses of people that daily pass back and forth between San Francisco and Oakland, Berkley and Alameda.

The dimensions of the boat are as follows:

Length over all, 240 ft.
Breadth moulded, 42 ft.
Breadth over guards, 62 ft. 7 in.
Depth moulded, 19 ft. 6 in.
Depth loaded, 11 ft. 6 in.

The speed of the boat is 13 knots.

The boiler plant consists of two Babcock and Wilcox water tube boilers. These boilers have a total heating surface of 5000 sq. ft., and will generate a steam pressure of 225 lb. per square inch. They are equipped with superheaters capable of raising the temperature of the steam 65 deg. F. above normal. The boilers are fitted with Coen oil burners working under normal draft and are guaranteed to supply steam at 210 lb. per square inch and 50 deg. F. superheat.

The propelling equipment consists of a steam turbine geared to a direct-current generator which furnishes power to the two main motors, one on each propeller shaft, and starting control system for both generator and motors. There are also several electrically operated engine room auxiliaries. Power for these auxiliaries as well as for the general lighting of the boat is obtained from a small generator which is direct connected to the main turbine-driven generator. For port use, and when the main unit is shut down, the auxiliary power is obtained from one of two 35-kw. turbine-driven direct-current generators.

The main generator is rated 1000 kw. 500 volts, is shunt wound, and has a considerable overload capacity for short periods. It obtains its excitation from the exciter which is direct connected to it. The main motors are each rated 1200 h.p., 125 r.p.m., 500 volts. They are located at opposite ends of the boat and are direct coupled to the two independent propeller shafts. Under normal operation, one motor drives the stern propeller at 125 r.p.m. and the other motor, the bow propeller, at 100 r.p.m. When the ferryboat makes its return trip the speed relations of the two motors are reversed so that the stern propeller which formerly was turning 100 r.p.m. now is turning 125 r.p.m., and the former stern propeller which now is the bow propeller is turning 100 r.p.m. The electrical connections are so made that whichever happens to be the bow propeller driving motor for the time being will automatically take the speed corresponding to that which gives zero slip on the bow propeller, thus increasing the propulsion efficiency. The stern motor at the same time will automatically take over the duty of driving the ship at whatever speed is called for from the bridge.

This method of driving the propellers is a complete departure from that heretofore used with reciprocating engines when the engine is connected to a continuous shaft through the length of the ship and both propellers are always revolving at the same speed.

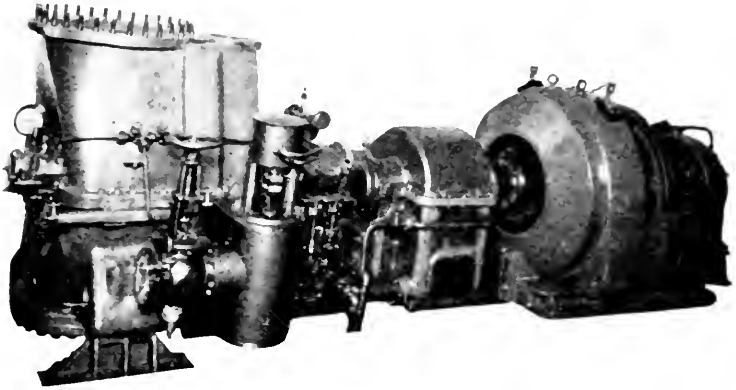

Fig. 1. 1100-kw. Curtis Steam Turbine Geared to a 1000-kw. Direct-current Generator and a 75-kw. Auxiliary Generator, Ferryboat *Hayward*

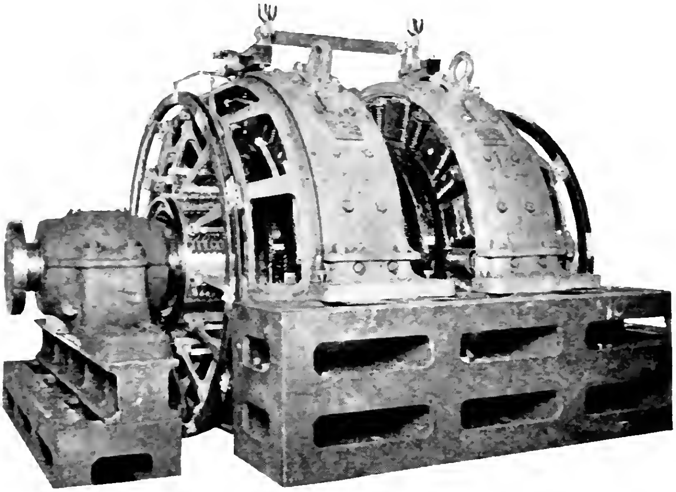

Fig. 2. 1200-h.p., 100/125-r.p.m., 500-volt Shunt-wound Double-armature Propulsion Motor, on Test Blocks, for Ferryboat *Hayward*. Two of these motors receive power from the generator shown in Fig. 1

The main control equipment consists of two parts—a panel and a controlling rheostat. The panel carries the switches for the motors, generator and the necessary overload and interlocking device. The controlling rheostat consists of a suitable dial rheostat and resistances for varying the excitation of the main generator, which results in varying the speed of the propelling motors. In the middle of the panel are two field switches, one for each motor, mounted horizontally. Between these two, and in a vertical position, is located the control and excitation switch which is so constructed that it must be opened before the other two switches can be opened. This arrangement insures against accidental opening of motor fields under load. The two motor field switches are triple-pole, single-throw, two of the knife blades having the same polarity, one supplying the motor field, and the other the holding coil of the motor line contactor. This prevents the closing of the motor line contactor unless the field switch is closed.

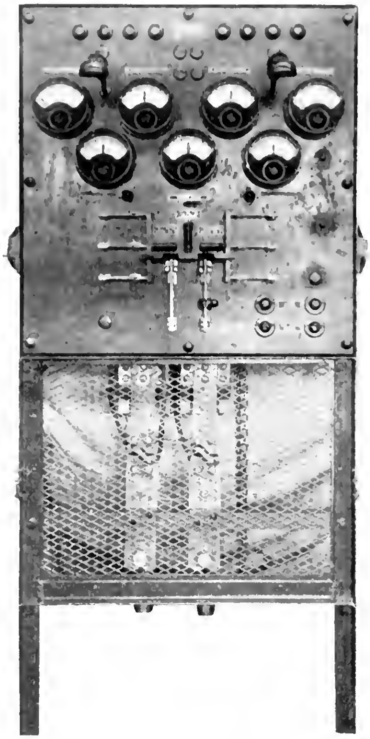

Fig. 3. Front View of Control Panel for the Propelling Motors and Generator Shown in Figs. 1 and 2

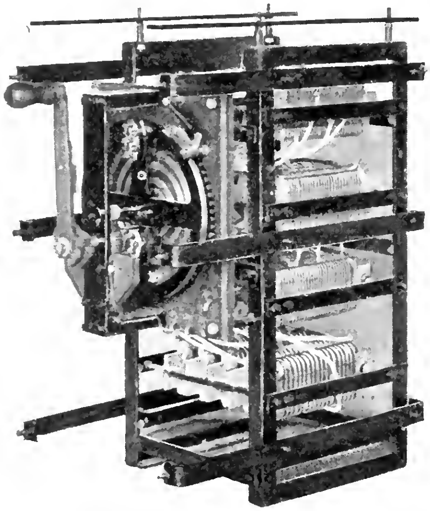

Fig. 4. Main Controlling Rheostat, with Covering Removed

Increasing or decreasing the revolutions of the propeller, as well as reversing its direction of rotation, are all obtained by means of the potentiometer type of rheostat, Fig. 4, which is connected across the field of the main generator. This rheostat consists of a bank of resistors mounted in a rugged angle iron frame with a dial switch built up on an ebony asbestos base. The whole structure is suitably covered by a sheet metal box covering not shown in the photograph. This rheostat is located in the engine room. Communication between the bridge and the engine room is obtained by means of the usual type of ship's telegraph.

The total weight of the propelling equipment is 212,000 lb.

It was on account of the reliable and successful operation and ease of maneuvering obtained with the turbine electric machinery of several large cargo boats, as well as of battleships and coast guard cutters, that the owners decided to equip these two ferryboats with this form of drive.

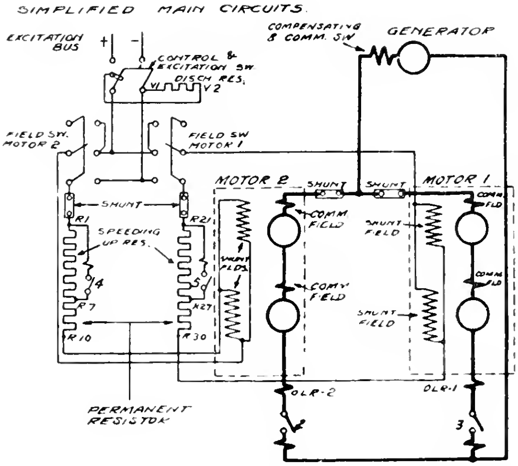

Fig. 5. Simplified Diagram of the Main Circuits of the Propelling Machinery of the Ferryboat *Hayward*

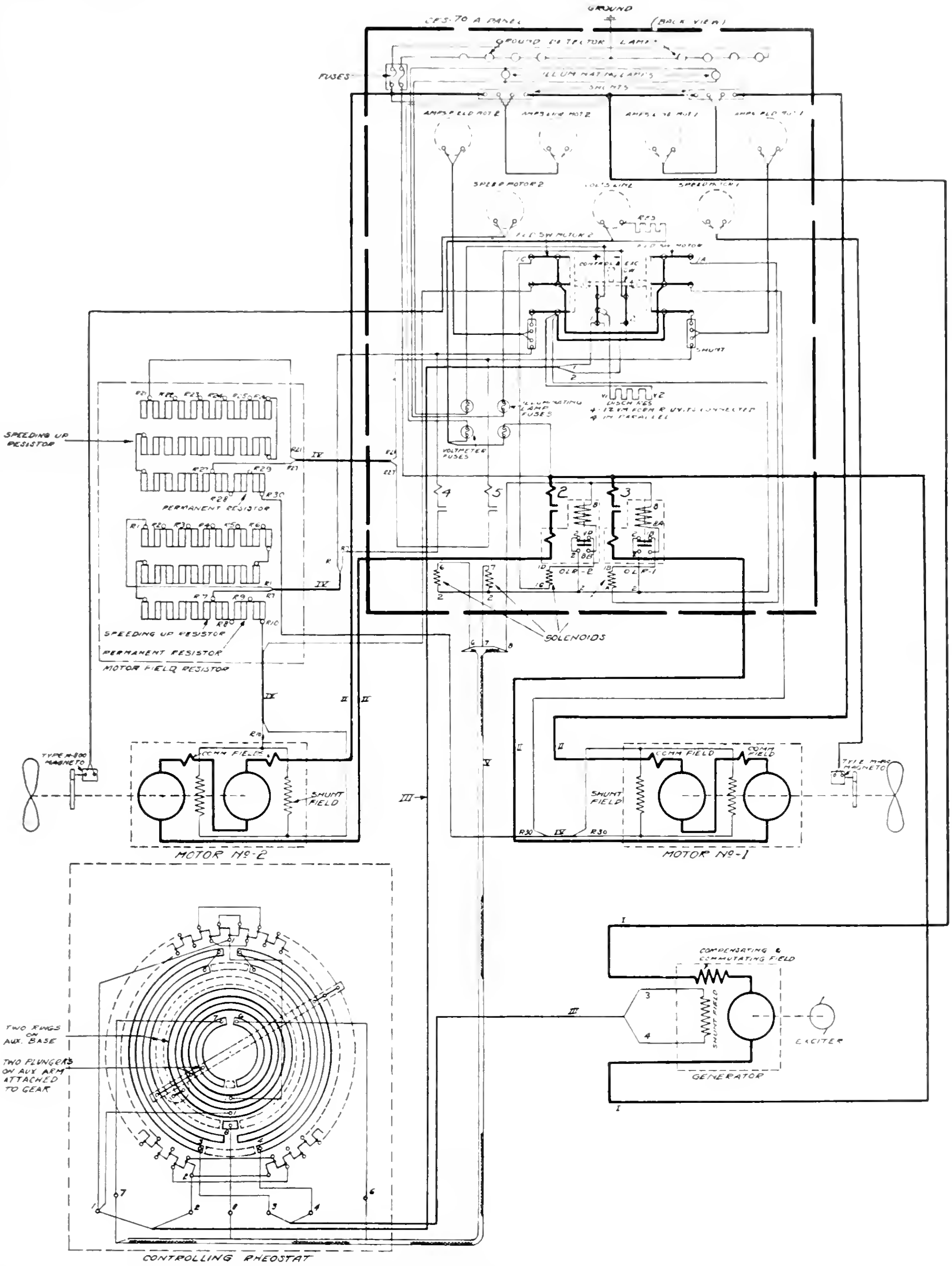

Fig. 6. Complete Diagram of Connections Between the Two Propelling Motors and the Main Generator. Above motor No. 2 are shown the speeding up resistors for the stern or driving motor

Cooling of Turbine Generators

PART III

PHYSICAL CONSIDERATIONS AND DESIGN OF SURFACE AIR COOLERS

By A. R. Smith

Construction Engineering Department, General Electric Company

The first article of this series dealing with the various ways of cooling air when re-circulated was published in our issue of December, 1922, and the second part covering heat transfer in surface air coolers appeared in our February, 1923, number. In this, the third part, the author discusses at considerable length the details of design. This series will be concluded with an article discussing the economies of using surface air coolers and heaters in steam power plants.—Editor.

Introduction

The introduction of surface air coolers for cooling the air from turbine generators represents such a departure from previous methods that the consensus of opinion of many engineers was that these coolers should not only have a large factor of safety in the amount of cooling surface, but that they should be substantially constructed in order to give reliable service and have a low maintenance cost. The investment cost of a first class cooling system is relatively small, when compared with the cost of the turbine generator, and it is obvious that continuity of service of a turbine generator should not be jeopardized by an apparent trivial saving in the construction of the cooler. These fundamentals were kept in mind in designing the present type of coolers with the result that only high class materials were employed and construction practice long in use for surface condensers was followed as closely as possible so as to eliminate experimental features which might later be found detrimental.

Tubes

The size tube now used is ⅝ in. outside diameter, 18 B.W.G. wall and the material is either Muntz metal or Admiralty metal, as may be required. Three quarters or one inch diameter tubes may be used if the trade requires them but experience will show if there is any advantage in the use of larger tubes. The principal service advantage of larger tubes is that there should be less chance of fouling in cases where ordinary circulating water is used as the cooling medium. To offset this advantage the smaller tube allows the installation of a greater amount of cooling surface in the same space. The length of tubes will depend largely on the size of the generator. The indications at present are that tubes no longer than 10 ft. will be required. Long tubes are supported at the center so that the unsupported spans are not more than approximately 100 tube diameters.

The tubes are given the same rigid tests as required for surface condenser tubes so that they may be used successfully with salt water, raw water, or condensate. If the circulating water is reasonably good the life of the tubes should be so long as to make the maintenance expense almost nil. With salt water or acidulated water, the maintenance expense may be comparable to surface condenser conditions.

Fins

In order to get the maximum amount of cooling surface at the minimum expense and in the smallest space, the tubes are wound with copper fins spaced seven to the inch, and having an effective depth of ¼ in. The addition of fins increases the external radiating surface of a tube, which is the high resistance side, over six times. The amount of space occupied by these fins is extremely small and they present little interference to the flow of air. The fins are shouldered and soldered to the tube so that the joint presents no measurable drop in temperature or resistance to the flow of heat; furthermore, this substantial attachment makes certain that vibration and handling will not loosen the fin surface. The fins are flat and smooth so that all of the surface is in contact with the air stream and should therefore be swept clean of any dirt which may get into the system.

Tube Sheets

The tube sheets are made of rolled Muntz metal to obtain a non-porous tube sheet which will prevent water from seeping through into the air space. Tubes are expanded in the usual manner into the one tube sheet and are packed in the other by means of standard condenser ferrules and cotton lace. The packed ends will allow for individual expansion and contraction of tubes which may at times become stopped with foreign matter. If the flow of water in a single tube is shut off, the temperature of this tube will soon reach the temperature of the air and therefore be considerably hotter than the tubes immediately surrounding it.

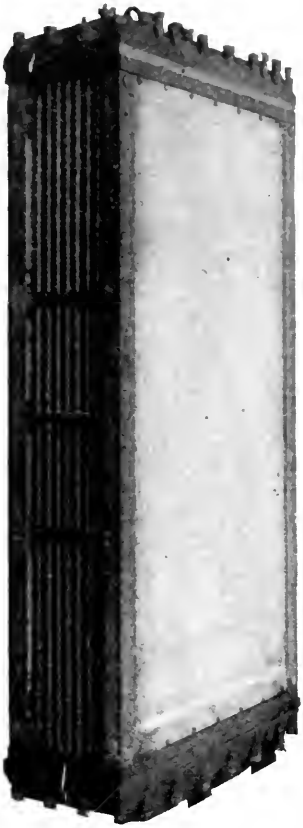

Fig. 1. A Cooler Section 9 Tubes Wide and 24 Tubes Deep. The more usual section will be 20 tubes wide and 12 to 18 tubes deep

Defective tubes are eliminated by tests before winding them. Tubes with internal stresses and likely to develop cracks when put in service are protected to a large extent by the tightly wound fins. If a defective tube is found after the cooler is put in service it should be plugged. If the circulating water is of fair quality no further tube trouble would be expected. If the water is so bad that it readily attacks the tubes then the chances are that most of the tubes will fail from dezincification and when this action becomes acute all of the tubes should be replaced.

When renewing tubes the tube sheet using ferrules must be removed. The tubes are held in position so that the tube sheet can be replaced without difficulty after the new tubes are in position. Frequent renewal of individual tubes are not anticipated. If a number of tubes must be renewed and general overhauling of each cooler section is desirable, the removal of one tube sheet and a careful inspection of the remaining tubes is a desirable procedure.

Water Boxes

Over each of the two tube sheets is bolted by means of studs and nuts, cast iron water boxes provided with a large inlet and outlet to reduce turbulence, which would tend to effect the distribution of water through the tubes. Partitions are cast integral with the water box so as to form any number of water passes that may be desired. The water boxes are set on rubber gaskets completely sealing the partitions as well as the external joint. The coolers are arranged so that the tube sheets form a part of the air duct which leaves the water boxes accessible so that the tubes can be inspected or cleaned with the least possible inconvenience.

The water boxes are shaped to carry through any entrained air and so far no trouble has been experienced from air binding, although vent cocks are provided for coolers which are to set in a vertical position.

Number of Water Passes

The plan so far has been to maintain a minimum water velocity through the tubes which would be in excess of the critical velocity. The maximum water velocity naturally depends on the pumping head permissible. The number of water passes depends on the number of tubes in the cooler and on whether condensate of circulating water is used. Eventually, the number of water passes will probably become more or less standard because the conditions under which turbine generators operate are not very different. For the present, however, any number of water passes can be obtained to meet conditions.

The flow of water with respect to the flow of air in so far as temperature difference is concerned is counter-current.

Air Pressure Drop

The resistance to the flow of air through the cooler is dependent on the air velocity and the depth of the cooler, the temperature of the air having only a slight effect on the drop in air pressure through the cooler. If a fixed amount of surface is so distributed that the air velocity is low, the depth of the cooler will naturally be reduced but the same amount of surface can be so distributed that the depth is considerably greater, which will result in a higher air velocity. When an approximation of the amount of surface is made, it is obvious that it can be so arranged, providing there is sufficient space, to obtain almost any resistance to air flow that may be desired.

When using the coolers in connection with turbine generators the available air pressure over and above that required by the generator and in the ducts is relatively small and may be different for various machines. It is, therefore, necessary to know how much of the total fan pressure is available for the cooler and the cooler must be proportioned accordingly. Ordinarily, the total drop through the cooler should not exceed 1 in. of water.

Resistance to the flow of air in large air ducts of moderate lengths is almost a negligible factor. Excessive pressure drops are the result of eddying and loss of velocity heads. In laying out any duct system, and especially those in connection with surface coolers, where all of the available pressure loss should be applied to the cooler, the ducts should be carefully designed and in many cases the ducts can be so designed that the duct loss can almost be neglected.

Fig. 2. To show how substantially the Fins are Attached to the Tubes, the fins of the perfect tube on the left were mutilated as shown in the center and were then trued up as shown at the right. No injured or broken joints appeared

Drop in Water Pressure

The loss of head or resistance to the flow of water is also a variable quantity and there is considerable latitude in regulating the total pressure drop. A velocity in the tubes of not less than 2 ft. per second is desired so as to keep the flow above the critical velocity. If a velocity of 5 or 6 ft. a second is attempted, the number of water passes are increased and the frict on head increases very rapidly.

Where the coolers utilize the condensate as a circulating medium then a relatively high velocity, say, of 4 or 4½ ft., is desirable when the turbine is operating at full load, so that at partial loads the velocity is more nearly normal. The total pressure drop in the cooler from the inlet to the outlet nozzle usually runs in the neighborhood of 20 ft.

Method of Cleaning Surface

The coolers should be installed in the air duct so that the water box at either end is accessible. With such an arrangement the water boxes can be removed and tubes cleaned, blown, washed, or turbined in exactly the same manner as the cleaning of a surface condenser. This cleaning process should be entirely unnecessary if condensate is used and unlike the surface condenser problem the small amount of water required by the surface cooler should, in most instances, make it perfectly feasible to filter or screen the water and thus avoid any cleaning process.

One of the purposes of a surface cooler is to insure a clean generator. If the system is sufficiently tight so that there is practically no deposit on the generator, then the external cooling surface of the cooler should also be clean. If the generator surfaces become fouled and clogged then the cooling system is defective. Should the coolers become dirty through any fault of design or operation they can be cleaned by submerging and boiling each section in a tank of water and washing soda.

Should any oil vapor flow into the circulating system it might condense only on the cooler and not on the generator. Although experience so far indicates that the oil vapor does condense even on the warm generator surfaces, any infiltration of oil vapor should be eliminated as far as possible.

Determination of Leaks

Judging from present experience, trouble from leaky tubes or joints is not anticipated except with air coolers employing salt water or fresh water containing destructive ingredients. Some provision, however, should be made to locate an occasional leak which can not be avoided. It is recommended that pilot holes or sight drains of some kind be provided in the air duct in such a location as will indicate the presence of water and if possible indicate which particular section is at fault.

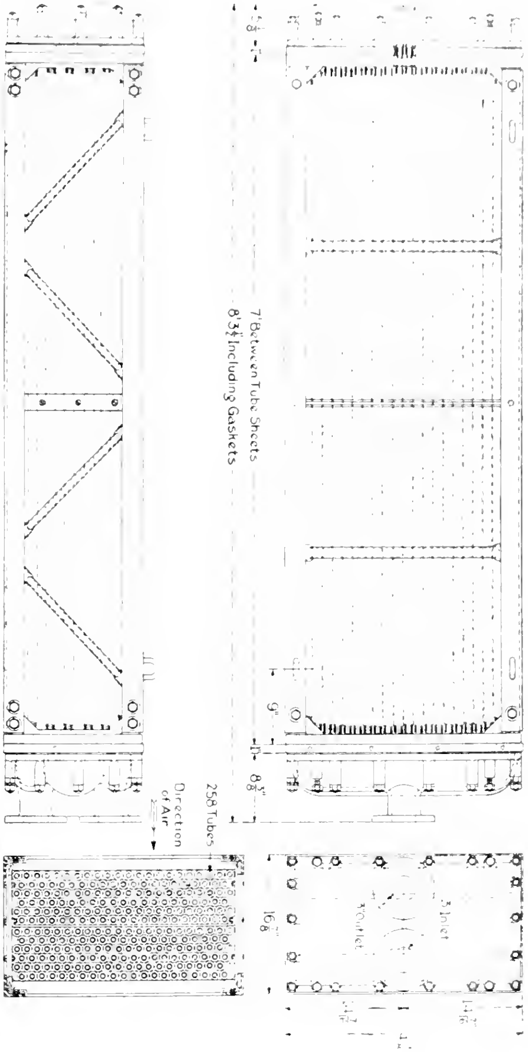

Fig. 3. General Construction of a Typical Cooler Section

If the duct drainage indicates a serious leak the trouble will probably be found in a bad tube which may be readily located as follows: Remove the two water boxes of the faulty section and then apply water or air under pressure to each tube by first plugging one end of the tube and inserting a nozzle which fits the other end of the tube. The nozzle connection should be provided with a gauge and a valve so that as soon as the tube is put under static pressure the supply can be shut off and any reduction in pressure on the gauge noted.

Fig. 4. Portion of One Water Box Removed to illustrate the uniformity of flow through the various tubes. This test was made to be sure there was no congestion in the water boxes

General Dimensions

The length of tube can be made to suit conditions. So far no tubes over 10 ft. in length have been proposed, largely because a cooler section having only a light frame might tend to twist and distort if the length is out of proportion to the width and depth. The number of tubes deep, that is, the number of rows of tubes in the direction of the flow of air, will probably vary from 12 to 20, depending on the requirements. The width of a cooler section is more or less arbitrary. It is preferred to make a complete cooler in several sections for the convenience of handling them and to simplify manufacture. There is nothing to be gained in making a single section for large machines and there are many disadvantages. A common width of section will range from 20 in. to 30 in.

Arrangement of Cooler Under Generator

The drawing in Fig. 5 will illustrate a common and convenient arrangement which is recommended and which can generally be obtained if the turbine foundation has not been constructed along other lines. The simplicity of air duct not only greatly reduces the cost, but has the important advantages of:

1. Reducing to a minimum the volume of air which would support combustion in case of a fire.

2. Making possible a system where the infiltration of air will be negligible.

It should be observed that with the arrangement shown individual cooler sections can be readily removed for inspection or repairs, while the water boxes are accessible, thus making possible the cleaning of tubes or the maintenance of tight joints possible without entering the air duct.

Arrangements of course are not limited to the one shown in the illustration. Coolers can be set in a horizontal or a vertical position but the arrangement recommended will assure a more uniform distribution of air to the cooler and will make available considerable basement floor area which generally can be used to advantage for many other purposes.

Advantages of Surface Coolers

In most cases the surface cooler presents a number of economical and operating advantages. To what extent these advantages may be capitalized depends of course upon local conditions. The common advantages are as follows:

1. If the air duct system contains but a small volume of air, no fire extinguisher should be necessary because the oxygen will be rapidly consumed and the fire smothered without requiring the attention of an operator or the operation of any dampers.

2. If the proper precautions are taken to prevent any material infiltration of air, the deposits in the machine or on the cooler should be insignificant. If a clean generator is maintained, the temperature rise of the winding above the incoming air temperature should not increase with age.

3. The volume of water required for cooling the air can be regulated because the flow of water is counter-current with respect to the flow of air. Where water is expensive it is therefore possible to economize on the quantity.

4. The pumping head or the amount of auxiliary power required is extremely low.

5. Where condensate can be employed, either wholly or in part, for the cooling of a generator, some or all of the generator losses are returned to the system in the form of heat.

General Limitations in Temperature

The surface cooler can be designed to cool the discharged air very close to the entering water temperature. This terminal difference, of course, depends on how much cooling surface is installed. Ordinarily, a terminal temperature difference of 15 deg. F. should be maintained. A lower temperature difference would be expected with the cooler surface perfectly clean. The ingoing air temperature to the generator should not exceed the standard ambient temperature of 40 deg. C. or 104 deg. F., and it is recommended that this be considered the extreme. Ordinarily the ingoing air temperature should not exceed about 35 deg. C. or 95 deg. F.

If the condensate temperature ever exceeds 85 deg. F., colder circulating water or service water should be substituted, during such periods. The coolers may be constructed in two sections, the first section using condensate the year round and the second section using a sufficient amount of cooler water during such periods as may be necessary, to maintain a discharge air temperature within the limits suggested above.

Two sources of water supply are recommended rather than the introduction of dampers to convert the re-circulating system to the open type. In case of the failure of either water supply the air temperature on the discharge side of the cooler will instantly rise to the temperature on the entrance side. Therefore, a reliable thermostat to announce such a condition should afford ample time for an operator to re-establish the water supply or to obtain it from the other source connected thereto. The temperature rise of the machine windings during such a period of course will be sluggish because of the thermal storage of the generator.

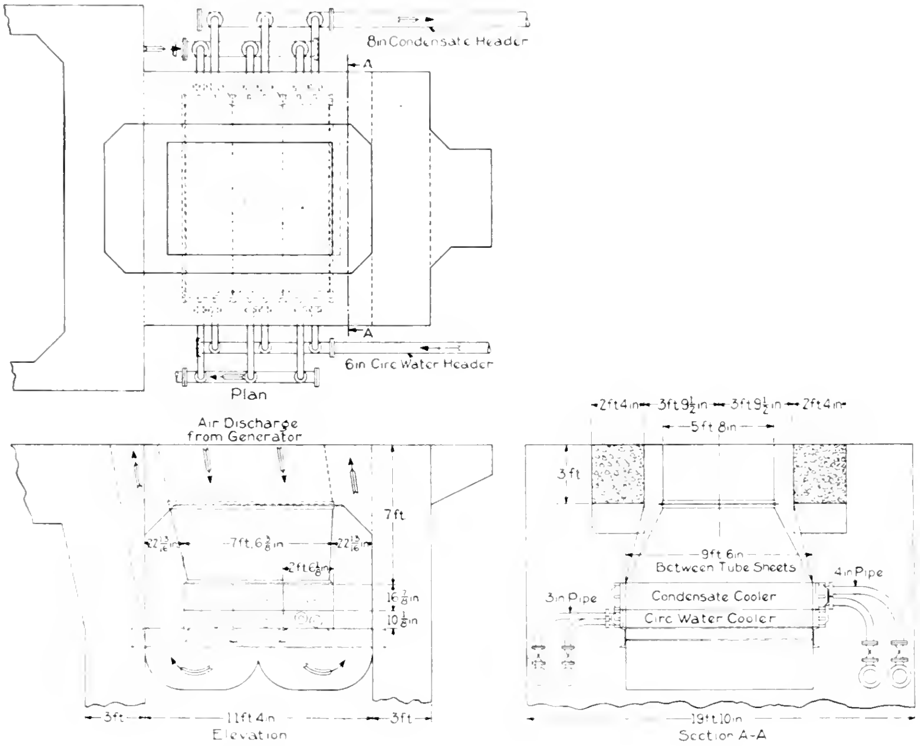

Fig. 5. Arrangement of Cooler and Generator Commonly Adopted

Eliminators

There may be arrangements adopted where the puncture of a tube might release water into the generator. Such a condition can be guarded against by the installation of water eliminators which have been developed especially for such a purpose. The introduction of eliminators, however, will introduce additional friction in the air circuit and it is recommended that the coolers be so located as to avoid the necessity of using eliminators. With the cooler sections located below the generator the spouting velocities of the water may prevent it from entering the generator winding even though it is assumed that such a leak develop at just the right point on the upper row of tubes.

Arc Welding of Cast Iron

PART II

By W. H. Namack

Chairman, Sub-committee on Electric Arc Welding of Cast Iron, Northern New York Section, A. W. S.

The study which the American Welding Society's Northern New York Section Committee on the Electric Arc Welding of Cast Iron gave to the problem of preventing the formation of the hard zone, or its removal, and its investigation to determine the relative weldability of various grades of cast iron led to the performance of a group of carefully conducted tests of seven commercial electrodes on two grades of cast iron at present in wide use. The following article is an abstract of the test results. Editor.

The problem of welding cast iron by means of the electric arc is not a single definite problem which might be solved easily by making a few tests. In fact the Committee has discussed it from every point of view and has found not one but many difficulties which confront the investigator from the start. The variables are many and the control of these variables is in some cases most difficult. The personal element is probably the greatest variable, but it can be made less dominating by proper selection in carrying out a series of tests although it is yet to be controlled in the practical application of arc welding.

SPECIAL INVESTIGATION BY THE COMMITTEE

In the course of its investigations, the Committee has considered the following points:

(1) Preparation of the parts to be welded.
(2) Prevention of slag inclusions in the weld metal deposited.
(3) Suitable values of current for the size of electrode employed.
(4) Method of deposition of the filler metal and its effect on the strength and hardness of the weld.
(5) Reversed polarity versus straight polarity.
(6) Effect of long versus short arc.
(7) Effect of speed of welding on the softness of the weld.
(8) Tests of electrodes with a view to ascertaining the most suitable materials, construction, and characteristics for use in welding various grades of cast iron.

Preparation

For the purpose of its investigation the Committee decided that in the preparation of the parts to be welded the single V is better than the double V because in actual service the use of the double V is in most cases practically impossible. A single V was therefore used in all of the Committee tests.

Slag Inclusions

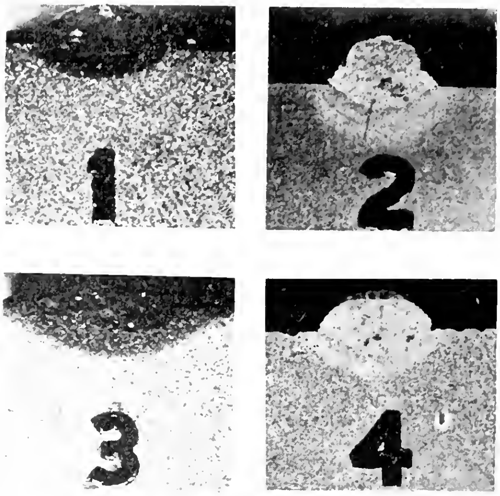

Fig. 1. Illustration showing Depth of Heat Penetration and Weld Penetration with Long and Short Arcs

It is usually agreed that gray cast iron is the most uncertain grade to weld. The difficulty seems to be due largely to the free carbon present which is called "kish." When welding with bare electrodes this "kish" causes a dark deposit to form on the weld metal. Chemical analysis indicates this deposit to be iron silicate or slag, which oftentimes causes a defective weld by lodging in the weld metal and forming what are called "slag inclusions." Two methods suggested to remove this "kish" seemed suitable to the Committee; viz., first, the surface to be welded may be subjected to a slight preliminary melting with the carbon arc, second, a high current value may be used in the welding process although the practicability of its use would depend upon the thickness of the parts to be welded and the skill of the operator. It would seem that the localization of heat has a tendency to create an annealing effect and the Committee believes that the data incorporated in the test results will tend to show that this proposition to use a high heat value in the welding operation has some worth.

Current Values

For cast iron welding by the metallic-arc process, the best results with average welding ability and a $\frac{1}{8}$-inch metal electrode on plates up to $\frac{3}{16}$-inch thickness were found to be secured with current up to 125 amp. and for a $\frac{5}{32}$-inch metal electrode current from 135 to 175 amp depending on the thickness of the plate.

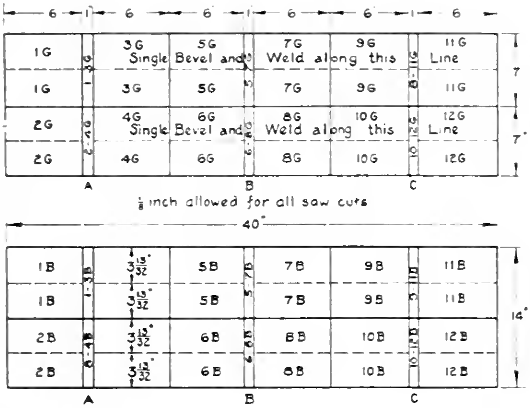

Fig. 2. Two Similar Examples of the Layout of Test Plates preparatory to cutting

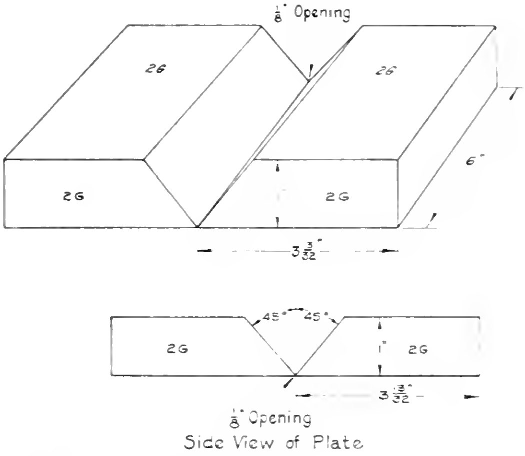

Fig. 3. Completion of Plates up to Time of Welding

Method of Deposition

The usual method of depositing the weld metal is to apply it in layers or beads lengthwise of the weld. In this way a series of interlocking layers is formed which, if brushed vigorously after each layer is deposited should give a clean weld Furthermore the heat can be kept low and consequently the expansion will be small. The deposition of metal by means of a single spiral layer was, however, strongly advocated and this latter method was employed in performing most of the Committee tests

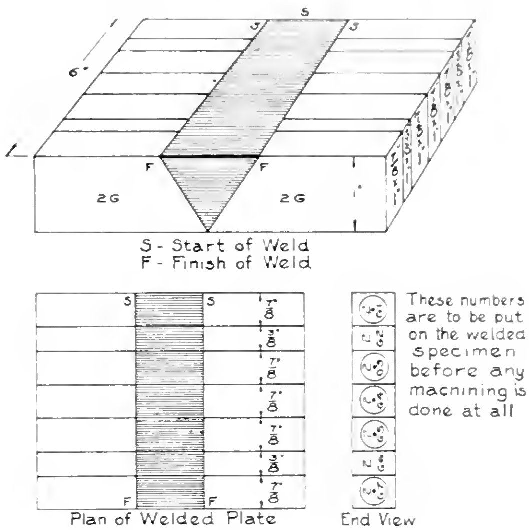

Fig 4 Layout of Welded Specimen preparatory to Machining the Test Bars

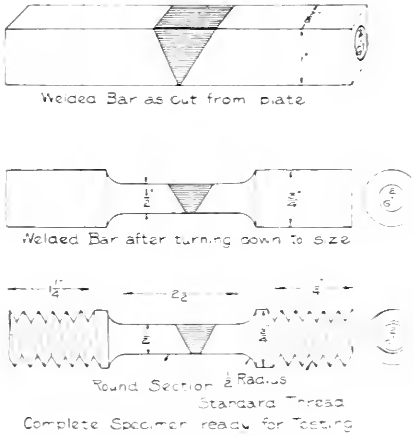

Fig. 5. Completion of Specimens for Testing

Polarity

Some members of the Committee advocated using reversed polarity to reduce the heating effect of the arc on the base metal but this suggestion was not adopted in the tests Probably for some electrodes and for some kinds of cast iron, better results can be obtained with reversed polarity.

Length of Arc

The Committee decided that an arc length not over 1/8 inch would give a deeper and more uniform penetration and would insure a stronger weld. In order to test this suggestion samples of long and short arc deposition on both steel and cast iron were analysed with the following result:

The Nitrogen Theory. Three zones were investigated by means of photomicrographs. Sections taken at the top of the bead, at the junction of the filler and base metals, and in the lower dark zone showed traces of nitrogen in the form of dark needles. This nitrogen or "nitride" as it is called was present in both the steel and cast-iron welds. The presence of carbon together with the nitride is the cause of the hardening effect. The hard zone in the steel weld is soft enough to be machineable and gives no trouble. The hard zone in the cast iron was very hard and not machineable.

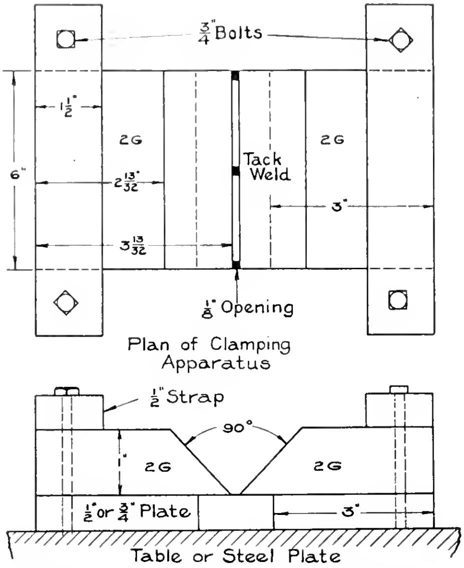

Fig. 6. Diagram of Clamping Apparatus Holding Test Plates preparatory to Welding

The four illustrations in Fig. 1 show the depth of penetration and hard zones: for two gray-cast-iron welds (No. 1 and 3) and two steel welds (No. 2 and 4).

Gray Cast Iron. Short Arc with bare electrode. Specimen No. 1, Fig. 1, shows that the filler metal is amalgamated nearly to the bottom of the black area and that the black area is somewhat more shallow than in the case of specimen No. 3.

Gray Cast Iron. Long Arc with bare electrode. Specimen No. 3, Fig. 1. The difference between "heat penetration" and "weld penetration" can be very clearly distinguished in this illustration. There are two hard zones, one at the bottom of the filler layer and the other at the lower edge of the dark area.

Steel. Short arc with bare electrode. Specimen No. 2, Fig. 1. The hard zones are present but are not as troublesome as in the case of cast iron due to the fact that there is not as much carbon present.

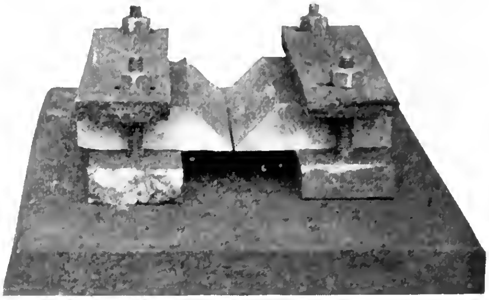

Fig. 7. Photograph of the Set-up, a sketch of which is shown in Fig. 6

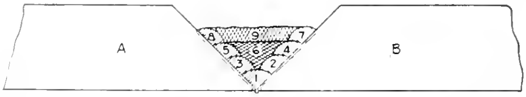

Fig. 8. Application of the Filler Metal by what is termed Method No. 2 in the tests

Steel. Long Arc with bare electrode. Specimen No. 4, Fig. 1. The different zones can be clearly distinguished here.

Speed of Welding *vs.* Softness

As the result of a series of tests the Committee concluded that the speed of welding did affect the softness of the deposited metal, the lower speed in the case of either straight or reversed polarity gave the softer deposit of metal. The hardness tests were made with a Shore Scleroscope and the following hardness numbers are the averages of about 50 readings each.*

	STRAIGHT POLARITY	REVERSED POLARITY
Slow	33	23
Fast	40	36

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* These should be regarded as of the nature of a hasty preliminary test which should be followed by a thoroughly careful and comprehensive research.

TABLE I

CHEMICAL ANALYSIS OF BASE METAL

	B Plate Per Cent	G Plate Per Cent
Total carbon	3.02	3.15
Graphitic carbon	2.52	2.96
Combined carbon	0.50	0.19
Silicon	1.90	2.28
Sulphur	0.102	0.104
Phosphorus	0.730	0.865
Manganese	0.88	0.55

TABLE II

KEY TO ELECTRODES USED IN WELDING TEST PLATES

Electrode	B Plates	G Plates
1	6B and 9B	1G
2	5B	2G and 4G
3	8B	
4	10B	
5	4B	5G
6	2B	8G
9	7B and 3B	9G

TABLE III

ELECTRODES AND CHARACTERISTICS

AVERAGE CURRENT 130-150 AMP., 20 VOLTS

The Chemical Analyses Were Made by J. H. Nead of the American Rolling Mills Co. The Characteristics Were Noted When the Test Plates Were Being Welded

Electrode	DESCRIPTION AND ANALYSIS OF ELECTRODES									Plate Used	Welding Characteristics
	C	Mn	Si	S	Ph	Cu	Ni	Cr	Fe		
1	Bare wire, $^5/_{32}$ in. by 14 in.									B	Arc unsteady but not as bad at the start of the weld as at the finish. Deposited metal stays molten over an area of about ½ of a square inch and boils while cooling. Hard to hold a short arc for this reason. Black scum formation stops the boiling. Wire varies in workability.
	0.100	0.466	0.040	0.025	0.039	0.056	Trace	....	.....		
2	Bare wire, $^5/_{32}$ in. by 14 in.									B	Large arc flame. Flashy arc with small pool of molten metal which cools quickly. Metal lays solid and deposits quite evenly. This electrode works nearly the same as if on a steel plate.
	0.010	0.012	Trace	0.037	0.021	0.062	Trace	.....	...		
3	Coated wire, $^5/_{32}$ in. by 14 in.									B	Arc uneven and sputters. Deposited metal puffs up and solidifies so that, when the arc passes over it after cooling, the deposited metal melts away showing a shell-like structure. Metal is deposited unevenly and gas holes appear as the metal cools. Large bright arc flame noticeable.
	....	1.65	0.080	0.025	0.021	27.27	68.25	....	2.29		
4	Coated wire, $^5/_{32}$ in. by 14 in.									B	Arc steady but sputters similar to a bare commercial electrode on a steel plate. Deposited metal lays evenly and solid but builds up slowly. A black scum forms as the metal cools but the deposited metal appears firm and solid. A smooth working electrode.
	0.010	0.010	Trace	0.040	0.019	0.032	Trace	Trace	....		
5	Coated wire, ⅛ in. by 18 in.									B	Steady arc similar to bare electrode on steel plate. Deposited metal seems to burn deep into the base metal and arc flame is quite noticeable. Wire burns away very fast. Electrodes were held at the third-points to prevent too rapid melting. No pool of metal to speak of. Black scum is not prominent.
	0.100	0.429	0.050	0.028	0.039	0.082	Trace	.....	.....		
6	Alloy wire, $^5/_{32}$ in. by . . in.									B	*Reversed polarity necessary.* Sputtering arc. Metal deposits by dropping off in globules and boils and bubbles while cooling. The metal does not spread but bunches up. As metal cools, numerous small gas holes appear and when the arc is passed over it again the surface melts away showing a honeycombed structure. The arc burns into the base metal. Protrusions are numerous.
	....	4.62	0.040	0.020	0.005	0.12	94.20	....	0.70		
7 8	These electrodes were not available for these tests.										
9	Composite, $^5/_{32}$ in. by 14 in.									B	Smooth steady arc with small flame. Metal solidifies very quickly and the pool of molten metal following the arc is hardly noticeable. Appearances indicate that the heat generated in the deposited metal is small. Metal deposits where desired and solidifies quickly. A brownish white coating appears on the surface of the finished weld.
	0.080	0.306	0.050	0.032	0.022	0.076	Trace	Trace	....		
										G	The arc characteristics were apparently the same as those already observed for the B plate, except that the arc was more unsteady and somewhat harder to maintain. The deposited metal did not stick as well to the G plate as it did to the B plate.

Electrodes

During the progress of its investigations, the Committee found that there were many different kinds of electrodes in use commercially for welding cast iron. It was therefore decided to investigate these as to their respective characteristics when employed in welding cast iron.

As a preliminary project, a program was outlined for investigating seven commercial electrodes of the following types: bare wire, flux covered, alloy metal, and alloyed flux electrodes.

TABLE IV

TIME REQUIRED AND METAL USED IN WELDING TEST PLATES

The weld groove was 6-in. long and 1-in. deep, beveled 90 deg., giving a volume of 6 cu. in. to top of plate. For electrode numbers see specifications.

B PLATE

Method as Per Specifications, 150 Amp., 20 Volts

			ELECTRODES		WEIGHT		
Electrode Number	Size Inches	Time Minutes	Number per Lb.	Number Used	Before, Oz.	After, Oz.	Metal Used, Oz.
1	$\frac{5}{32}$ by 14	41	14	25⅔	29⅓	3⅔	25.8
2	$\frac{5}{32}$ by 14	37	14	22	25.1	3.4	22.1
3	$\frac{5}{32}$ by 14	41	12	25	33⅓	3	30⅓
4	$\frac{5}{32}$ by 14	40	13½	23	27.3	4	23.3
5	⅛ by 18	52¼	16	26½	26.5	4	22.5
6	$\frac{5}{32}$ by ..	30	..	....	40	12	28.0
9	$\frac{5}{32}$ by 14	30	11	17	24.7	4	20.7
B AND G PLATES							
Method No. 2. 150 Amps., 15 Volts							
2 (G plate)	$\frac{5}{32}$ by 14	50	14	23	26.3	2.3	24
9 (B plate)	$\frac{5}{32}$ by 14	35	11	20	29.1	5.3	23.8
1 (B plate)	$\frac{5}{32}$ by 14	39	14	26	29.7	6.3	23.4
G PLATE							
Method as Per Specifications, 150 Amp., 20 Volts							
1	$\frac{5}{32}$ by 14	40	14	22	25.1	2.9	22.2
2	$\frac{5}{32}$ by 14	47	14	27	30.9	3.4	27.5
6	$\frac{5}{32}$ by ..	32	....	....	34	7	27
9	$\frac{5}{32}$ by 14	33	11	18	26.2	3.3	22.9
5	⅛ by 18	46	16	23	23	2	21

The Committee's investigations were confined wholly to testing these seven electrodes in accordance with the Specifications for Tests which are given in the following.

After careful deliberation and consideration of the various elements and factors involved, the following program was adopted by the Committee as constituting a basis for a preliminary investigation, and in the belief that (with the many modifications which would doubtless be suggested as experience accumulated) it might come to be accepted as a *Standard Method of Procedure* for further investigations of this character.

SPECIFICATIONS FOR TESTING COMMERCIAL ELECTRODES

Size of Plate

The size of plate shall be 40 by 14 by 1 inch. One plate shall be cast for each grade of iron to be tested.

Method of Casting

The plates for test shall be cast flat in a green sand mold.

Chemical Analysis and Tensile Strength of Each Material

These data shall be obtained from the coupon bars cut from the plates as shown by 2-4G, 2-4B, etc., in Fig. 2, and compared with the data obtained from the foundry test records.

Heat Treatment

The plates shall be allowed to cool overnight in the sand of the mold to avoid any

TABLE V

MACHINIST'S REMARKS ON CUTTING THE WELDED PLATES

Plate	Electrode No.	Time of Cutting, Hours	Remarks on Cutting
1 G	1	4¼	Plate cut under difficulties although the welded portion was no harder than usual Rather stringy metal in the welded portion causing saw teeth to clog especially after cutting the first three test pieces. From the fourth test piece, the balance of plate required two cuts on each test piece before taking the entire thickness. The machine had to be stopped quite frequently to remove chips from the saw teeth, when passing through the welded section.
2 G	2	3½	First four test pieces were cut using same saw as was used in cutting the six test pieces from Plate 5 B. While cutting the fifth test piece, the saw struck a real hard spot which took the entire cutting edge from the saw. A new saw was used to complete the plate. This plate was quite hard in general but was able to cut through the entire thickness of each piece by raising and lowering the table to prevent stopping of saw.
4 G	2 Method No. 2	5¾	Plate was exceedingly hard, requiring the use of three saws and taking two cuts on each test piece. Entire plate was hard not only in welded portion but also through the cast iron.
5 G	5	3¾	Plate machined fairly well but metal at junction of filler and base metals was hard. The hard junction and crust on top of welded section made it necessary to raise and lower the table to prevent the saw from stopping. One saw was used on the entire plate.
8 G	6	3	Plate cut very good. Entire thickness of plate was taken in one cut using same saw as was used on Plate 8 B. The weld section was no harder than usual.
9 G	9	3	Entire plate was cut with one saw taking the entire thickness of the plate in one cut. The welded section had no effect on the saw in the least aside from the effect of the scale and grit.
2 B	6	3	Plate cut excellently, being cut into test pieces with one saw taking the entire thickness in one cut. Welded section had no effect on the saw aside from the effect of the scale and grit.
3 B	9 Method No. 2	8⅔	Entire plate was very, very. exceedingly hard requiring the use of 14 saws before the plate was completed. One saw was totally destroyed as it pulled in two under the strain of the hard welded sections. Plate was raised and lowered repeatedly to allow saw to cut through.
4 B	5	3¼	Entire plate was machined with same saw as was used on Plate 2 B, taking entire thickness of plate per cut up to last test piece which required two cuts. The welded portion of the whole plate was real hard and probably be hard to turn
5 B	2	3¾	The first cut was very hard requiring the use of three saws and taking two cuts for the test piece. After securing the first piece a sharp saw was placed on the arbor and the entire plate completed with it, taking the entire thickness of plate at one cut.
6 B	1	3	Plate machined very nicely. Used same saw that finished last two cuts on Plate 2 G taking entire thickness of plate per cut. In fact this plate machined similar to Plate 7 B although the welded section was much harder.
7 B	9	3	Plate machined excellently, the entire plate being cut into test pieces with one saw taking the entire thickness of the plate per cut. The welded section did not seem to affect the saw in the least.
8 B	3	3	A sharp saw was placed on the arbor and the entire plate was machined with it taking the entire thickness of the plate in one cut. Aside from the welded portion being somewhat hard the plate worked up excellently.
9 B	1 Method No. 2	3	Plate machined excellently taking the entire thickness of the plate in one cut. The welded portion did not seem to be very hard but rather tough.
10 B	4	7	First cut was extremely hard, requiring five different cuts to go through the plate, practically destroying the saw. The entire plate was quite hard in general, requiring three cuts or more to each test piece also the changing of saws for each piece until the last cut which was made through the entire plate in one cut.

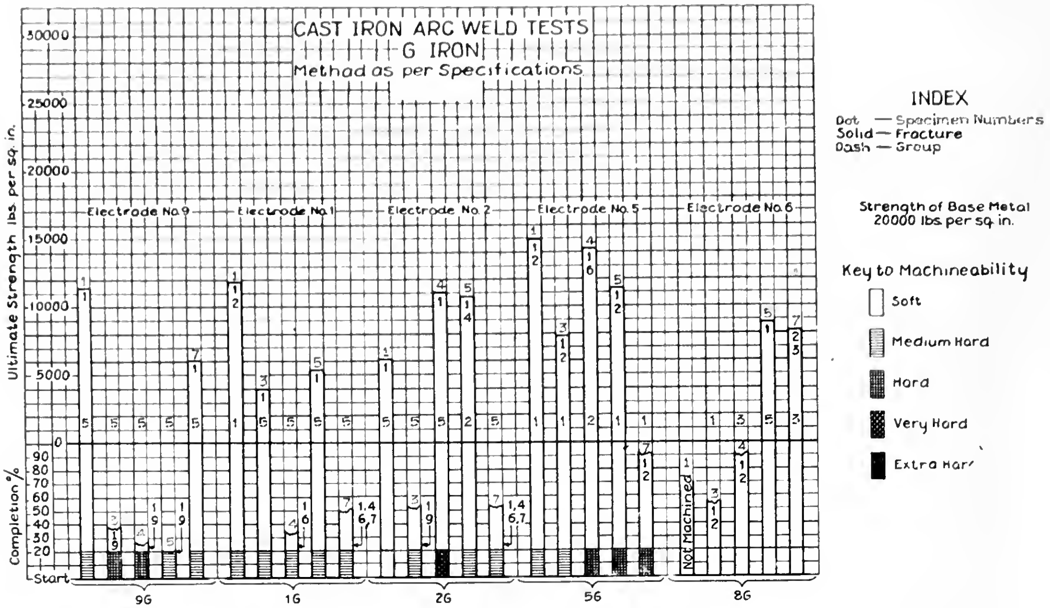


Fig. 9. Classification of G Iron Test Bars with respect to Machineability and Tensile Strength

1. Along line of weld
2. Perpendicular to axis of test piece
3. Honeycomb structure
4. Coarse granular
5. Crystalline
6. Slag inclusions
7. Blowholes
8. Broke in threads
9. Uneven break

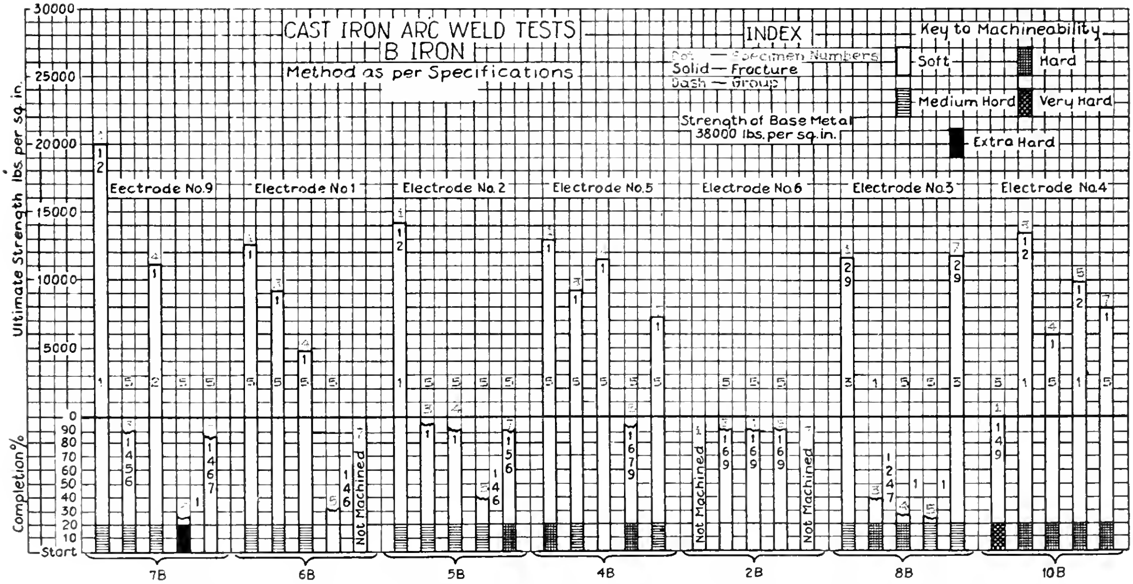


Fig. 10. Classification of B Iron Test Bars with respect to Machineability and Tensile Strength

1. Along line of weld
2. Perpendicular to axis of test piece
3. Honeycomb structure
4. Coarse granular
5. Crystalline
6. Slag inclusions
7. Blowholes
8. Broke in threads
9. Uneven break

chilling action. No heat treatment shall be given to any plate.

Size of Samples

For Welding

Plates shall be laid out as shown in Fig. 2. (Two examples given.)

For Testing of Parent Metal

The sample test bars shall be prepared according to the specifications of the A. S. T. M. from the coupons cut from the plate shown in Fig. 2.

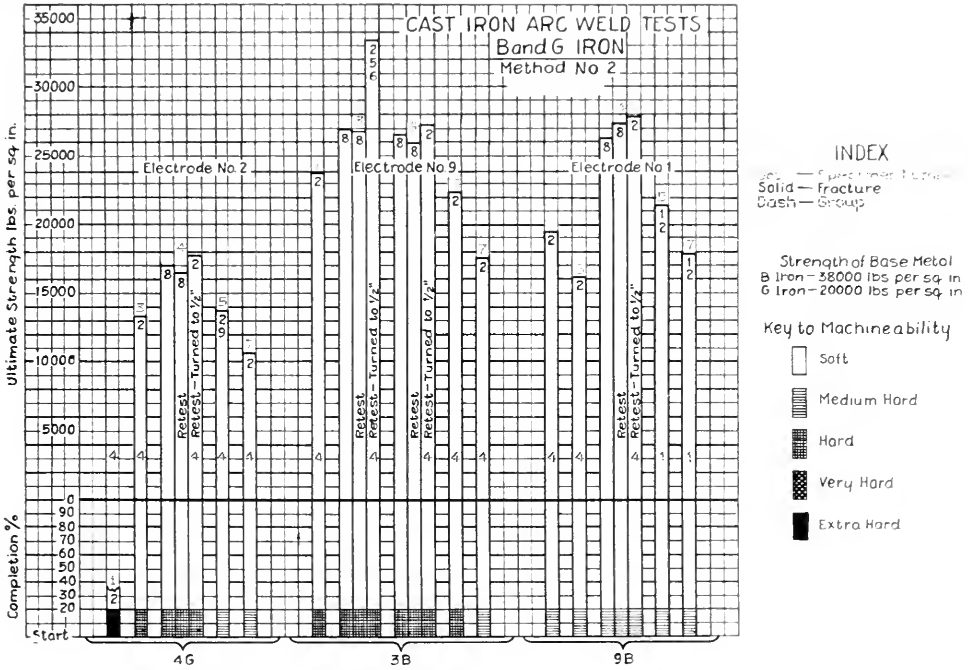


Fig. 11. Classification of B and G Iron Test Bars (welded by Method No. 2) with respect to Machineability and Tensile Strength

1.	Along line of weld	4.	Coarse granular	7.	Blowholes
2.	Perpendicular to axis of test piece	5.	Crystalline	8.	Broke in threads
3.	Honeycomb structure	6.	Slag inclusions	9.	Uneven break

Preparation of Samples

Cutting

Plates shall be marked for identification as shown in Fig. 2, and then cut as shown in Figs. 2 and 3. As an extra precaution, after cutting, the samples shall have the same marking stamped on one short edge of each as is stamped on the surface.

Bevelling

Single bevel, 45 deg. to the center, as shown in Fig. 3.

Method of Welding

Kind, Analysis, and Size of Electrodes

The following electrodes shall be used:

(1) Bare wire
(2) Bare wire
(3) Coated wire
(4) Coated wire
(5) Coated wire
(6) Alloy wire
(7) Alloy wire
(8) Alloy wire
(9) Composite electrode

These electrodes shall be 5/32 in. in diameter, and a chemical analysis of each shall be made.

Current

Preferably 150 amp. in each test. The current actually used shall be recorded.

Polarity

Straight polarity (work positive and electrode negative) with all electrodes, and also additional samples with reversed polarity on the non-ferrous electrodes.

Clamping

Plates to be clamped as shown in Figs. 6 and 7, and tacked at both ends and the center before the weld is started. These tack welds shall each be a single bead approximately ½ in. long.

Number of Layers

One spiral layer only shall be deposited to fill the groove in each test. The surface of the deposited material shall extend approximately ⅛ in. above the surface of the base material.

Fig. 12. Four Welded Specimens, which broke in the threads on the first two tests, turned to one-half inch diameter for the third test

Cleaning

The surface of the deposited metal shall be kept clear of all scale at all times by brushing with a wire brush.

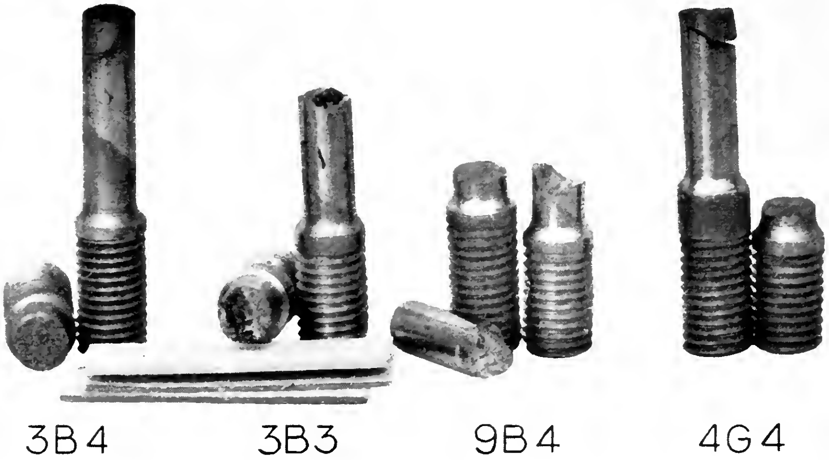


Fig. 13. Four Welded Specimens of Fig. 12 after Testing, showing Fractures

Remarks

After the weld has been completed the clamps shall be left in place until one's hand can be held on the weld without discomfort. No artifical cooling shall be applied.

Just before the clamps are removed the welder shall stamp an "S" on the surface of the plate at the start of the weld and an "F" at the finish. A record shall be kept of the number stamped on the sample, the type of electrode used, the welding current, the time required for making the weld, the arc characteristics of each electrode, and the number, length, and total weight of electrodes used on each sample, together with the weight of scrap ends.

Testing

The plates shall be laid out to be cut crosswise of the weld into five bars ⅞ by 1 in., and two bars ⅜ by 1 in., as shown in Fig. 4. Lathe centers shall be drilled so that they will come in the center of the end of each of the ⅞ by 1 in. bars.

Then identifying numbers shall be stamped around the lathe centers on the ⅞ by 1 in. bars so that these numbers will appear on each end of each bar after the ends are turned down to ¾ in. in diameter, and also on the ends of each of the ⅜ by 1 in. bars. The identifying numbers shall consist of the number on the sample plate followed by a numeral, this numeral being (1) for the bar cut from the sample plate at the start of the weld and (7) for the bar cut from the sample plate at the finish of the weld, the intervening bars being numbered consecutively, as shown in Fig. 4.

The sample plates shall then be cut as laid out, and each ⅞ by 1 in. bar shall be machined as shown in Fig. 5, no machining being done on the ⅜ by 1 in. bars.

The machinist shall keep a record of the characteristics of all of the test specimens as regards machineability of the welded portion.

Tensile Strength Tests

Tensile strength tests shall be made on each of the round test bars in accordance with A. S. T. M. Standards.

Hardness Tests

Scleroscopic hardness readings shall be taken on the deposited metal, at the junction of the deposited metal and the parent metal, and on the parent metal, on each of the 3/8 by 1 in. test bars.

Microscopic and Chemical Analysis

After hardness tests have been completed on the 3/8 by 1 in. test bars, these shall be used to obtain photomicrographs of the junction of the deposited metal and the base metal to determine, if possible, the cause of any excessive hardness. No chemical analysis of the deposited metal shall be made unless it is determined, after the various other tests, that such analysis would be desirable on any of the specimens.

Fig. 14. Typical Fractures of Tensile Specimens arranged in groups

Reports

All data collected, with the complete history of each specimen, shall be shown on the final report, together with such conclusions as may be drawn.

THE COMMITTEE'S TESTS

The Committee selected two different grades of cast iron as base material for the tests. These two grades of iron are identified by the letters B and G and their trade names are turbine or cylinder iron, and gray cast iron, respectively. Their chemical analyses are given in Table I.

Two methods of depositing the filler metal were used in these tests, namely, that as described in the Specifications and another, illustrated in Fig. 8, which will be referred to as Method No. 2. It will be noted that this latter method allows the operator to deposit steel on the surface of the cast iron better and insures better penetration since the electrode can more easily be held perpendicular to the surface of the base metal while putting on each bead. The procedure is as follows: The parts *A* and *B* are first joined together by bead *1*. Then beads *2* and *3* are laid on so that they do not quite touch. Beads *4* and *5* are next deposited and then filling *6* is laid down. More beads are laid on the cast iron and the filling-in process is continued so that the whole weld is made up of a succession of layers. The advantage claimed for this method is that the deposition of the filler metal by stages has a great tendency to anneal the deposited metal below the particular stage which is being deposited and in this way a softer weld is obtained.

The method referred to in the Specifications consists of depositing the filler metal in one spiral layer after the parts *A* and *B* had been

TABLE VI

SUMMARY OF TESTS ON GRAY CAST IRON (G PLATES)

Sample No.	Electrode Used	Weld Appearance Before Testing	Machineability	DIMENSIONS		LOAD AT FAILURE		Group No.	Fracture Location	Key to Fracture
				Diam. Inches	Area Sq. In.	Lb.	Lb. Per Sq. In.			
2-4G				0.5	0.196	4380	22400	Base Metal		(a) Along line of weld. (b) Perpendicular to axis of test piece. (c) Honeycomb structure. (d) Coarse granular. (e) Crystalline. (f) Slag inclusions. (g) Blow holes. (h) Broke in threads. (i) Uneven break. (j) In the cast iron. (k) In the weld.
9-11G				0.5	0.196	3300	16850			
1G1	1	Poor	Medium hard	0.757	0.4501	5305	11800	1	ab	
1G3	1	Poor	Medium hard	0.747	0.4385	1725	3900	5	a	
1G4	1		Medium hard. Broke (2nd cut)					5	af	
1G5	1	Poor	Medium hard	0.762	0.4560	2420	5300	5	a	
1G7	1		Medium hard. Broke (4th cut)					5	adfg	
2G1	2	Fair	Soft	0.75	0.442	2660	6020	5	a	
2G3	2		Medium hard. Broke (3rd or 4th cut) nearly ¾ in.					5	ai	
2G4	2	Fair	Very hard	0.759	0.4525	4925	10900	5	a	
2G5	2	Poor	Medium hard	0.754	0.4465	4750	10600	2	ad	
2G7	2		Medium hard. Broke (3rd or 4th cut) about $\frac{5}{16}$ in.					5	adfg	
4G1	2*		Hardest of all samples. Broke (2nd cut)					4	bj	
4G3	2*	Good	Hard	0.752	0.4442	5915	13300	4	bj	
4G4	2*	Good	Hard	0.756	0.4489	7200	17000	4	h	
4G4	2*	Good	Hard	0.756	0.4489	7400	16500	4	h	
4G4	2*	Good	Hard	0.5655	0.2512	4440	17700	4	abj	
4G5	2*	Good	Medium hard	0.754	0.4465	6130	13700	4	bijk	
4G7	2*	Fair	Medium hard	0.749	0.4406	4675	10600	4	bj	
5G1	5	Fair	Medium hard	0.75	0.442	6550	14810	1	ab	
5G3	5	Poor	Medium hard	0.75	0.442	3410	7710	1	ab	
5G4	5	V.poor	Hard	0.75	0.442	6230	14100	2	af	
5G5	5	Poor	Hard	0.75	0.442	4950	11200	1	ab	
5G7	5		Hard. Broke (last cut)					1	ab	
8G1	6		Undersized. Not machined							
8G3	6		Soft. Broke					1	ab	
8G4	6		Soft. Broke (last cut)					3	ab	
8G5	6	V.poor	Soft	0.768	0.4633	4040	8700	1	a	
8G7	6	Poor	Soft	0.762	0.4560	3675	8100	3	bck	
9G1	9	Poor	Medium hard	0.755	0.4477	5040	11300	5	a	
9G3	9		Hard. Broke (2nd or 3rd cut)					5	ai	
9G4	9		Hard. Broke (1st cut)					5	ai	
9G5	9		Medium hard. Broke (putting in center mark)					5	ai	
9G7	9	Poor	Medium hard	0.762	0.4560	2735	6000	5	a	

* Method No. 2 used.

TABLE VII

SUMMARY OF TESTS ON TURBINE OR CYLINDER IRON (B Plates)

Sample No.	Electrode Used	Weld Appearance Before Testing	Machineability	DIMENSIONS		LOAD AT FAILURE		Group No.	Fracture Location	Key to Fracture
				Diam. Inches	Area Sq. In.	Lb.	Lb. Per Sq. In.			
2-4B				0.5000	0.1964	7490	38100	Base Metal		
9-11B				0.5	0.196	7630	38900			
2B1	6		Undersized. Not machined							See above.
2B3	6		Broke. Turned to ¾ in.					5	afi	
2B4	6		Broke							
2B5	6		Broke					5	i	
2B7	6		Undersized					5	i	

TABLE VII—(Cont'd)

Sample No.	Elec-trode Used	Weld Appear-ance Before Testing	Machineability	DIMENSIONS		LOAD AT FAILURE		Group No.	Fracture Location	Key to Fracture
				Diam. Inches	Area Sq. In.	Lb.	Lb. Per Sq. In.			
3B1	9*	Fair	Hard	0.761	0.4548	10755	23700	4	bj	
3B3	9*	Fair	Hard	0.753	0.4453	12000	26900	4	h	
3B3	9*	Fair	Hard	0.753	0.4453	11900	26700	4	h	
3B3	9*	Good	Hard	0.575	0.2597	7065	27200	4	bk	
3B4	9*	Fair	Hard	0.758	0.4513	11950	26500	4	h	(i) Uneven break. (j) In the cast iron. (k) In the weld.
3B4	9*	Fair	Hard	0.758	0.4513	11680	25900	4	h	
3B4	9*	Good	Hard	0.570	0.2552	8540	33360	4	bj	
3B5	9*	Fair	Hard	0.741	0.4313	9620	22300	4	bj	
3B7	9*	Good	Medium hard	0.753	0.4453	7880	17450	4	bjk	
4B1	5	Poor	Hard	0.755	0.4477	5765	12900	5	a	
4B3	5	Poor	Medium	0.750	0.442	4050	9180	5	a	
4B4	5	Poor	Soft	0.755	0.4477	5110	11400	5	a	
4B5	5		Hard. Broke (all but threaded)					5	afgi	
4B7	5	V. poor	Medium hard	0.755	0.4477	3200	7200	5	a	
5B1	2	Poor	Medium hard	0.75	0.442	6250	14150	1	ab	
5B3	2		Broke. Nearly complete					5	a	
5B4	2		Medium. Broke (last cut)					5	a	
5B5	2		Medium. Broke (2nd or 3rd cut)					5	adf	
5B7	2		Hard. Broke (last cut)					5	aef	
6B1	1	Poor	Medium hard	0.749	0.4406	5540	12600	5	a	(e) Crystaline. (f) Slag inclusions. (g) Blow holes. (h) Broke in threads.
6B3	1	Poor	Medium hard	0.742	0.4324	3960	9200	5	a	
6B4	1	Poor	Medium hard	0.752	0.4442	2130	4800	5	a	
6B5	1		Soft. Broke (2nd cut)					5	adf	
6B7	1		Undersized. Not machined							
7B1	9	Poor	Medium hard	0.749	0.4406	8850	20100	1	a	
7B3	9		Broke (nearly complete threaded)					5	adef	
7B4	9	Poor	Medium hard	0.741	0.4313	4850	11200	2	a	
7B5	9		Harder than flint. Broke (1st or 2nd cut)					4	a	
7B7	9		Broke (turning down last cut apparently soft)					5	adfg	
8B1	3	Poor	Medium	0.755	0.4477	5175	11600	3	bik	
8B3	3		Hard. Broke (2nd or 3rd cut) to $\frac{15}{16}$ in.)					1	abdg	
8B4	3		Hard. Broke (1st cut complete) just started					5	ik	
8B5	3		Medium. Broke (1st cut)					5	ik	
8B7	3	Fair	Medium	0.725	0.4128	4830	11700	3	bik	
9B1	1*	Fair	Medium hard	0.748	0.4394	8525	19400	4	bk	(a) Along line of weld. (b) Perpendicular to axis of test piece. (c) Honeycomb structure. (d) Coarse granular.
9B3	1*	Good	Medium hard	0.750	0.4418	7100	16100	4	bj	
9B4	1*	Good	Medium hard	0.758	0.4513	11810	26200	4	h	
9B4	1*	Good	Medium hard	0.758	0.4513	12320	27300	4	h	
9B4	1*	Good	Medium hard	0.575	0.2597	7230	27800	4	bj	
9B5	1*	Good	Medium hard	0.75	0.442	9420	21300	1	ab	
9B7	1*	Fair	Medium hard	0.748	0.4394	7820	17800	1	ab	
10B1	4	Poor	Very hard. Broke two blows on edge of table					5	a	
10B3	4	Good		0.75	0.442	5920	13400	1	ab	
10B4	4	Poor	Hard	0.762	0.4560	2960	5900	5	a	
10B5	4	Poor	Hard	0.752	0.4442	4360	9800	1	ab	
10B7	4	V. poor	Hard	0.759	0.4525	3590	7900	5	a	

* Method No. 2 used.

joined by a single bead at the bottom of the groove. This method is claimed to prevent slag inclusions and eliminate hard spots in the weld metal. The results of the tests did not confirm the superiority of this method.

It will be noted from Table II that the *number of the electrode used has no connection at all with the number of the plate* which was welded by that particular electrode.

In making the welds, the test plates were set up as shown in Fig. 7. During the welding operation the characteristics of the arc were carefully observed. The observations are recorded in Table III. A study of this table

TABLE VIII

CHARACTER OF FRACTURE AFTER BREAKING SPECIMENS IN TENSILE TEST

(See Fig. 14)

GROUP 1

Fracture partly through the cast iron at right angles to specimen and then along the line of weld.

1 G 1	25 per cent through cast iron. Weld pulled-out some cast iron. 10 per cent burned metal
8 G 5	30 per cent through cast iron. Weld metal surface coarse granular
5 G 1	60 per cent through cast iron. Balance badly burned
10 B 5	20 per cent through cast iron. Large pigeon blue spot at edge of weld metal about ⅝ in. by ¼ in.
7 B 1	40 per cent through cast iron. Balance badly burned metal
9 B 7	40 per cent through cast iron. Burned metal lighter than 7 B 1
5 B 1	50 per cent through cast iron. About 15 per cent burned metal. Remainder grayish color with pockmarks
10 B 3	60 per cent through cast iron. Balance dark grayish metal
9 B 5	70 per cent through cast iron. Dark brown spots in weld metal. Flaw in base metal due to undersized bar before turning
5 G 5.	30 per cent through cast iron. Balance pockmarked, cat's paw structure
5 G 3	60 per cent through cast iron. Balance burned metal

GROUP 2

Similar to Group 1 except that break through cast iron was not at right angles to the test specimen but rather parallel to line of weld.

5 G 4	20 per cent through cast iron. 50 per cent good metal. Some slag
2 G 5	20 per cent through cast iron. Grayish brown granular surface
7 B 4	50 per cent through cast iron. Varicolored slag section

GROUP 3

Fracture at right angles to test specimen and very irregular on the surface. Break at center of weld.

8 B 1	Coarse granular and full of gas pockets. Very porous
8 B 7	Coarse granular and full of gas pockets. Very porous
8 G 7	Coarse granular and full of gas pockets. Very porous

GROUP 4

Fracture at right angles to specimen. Surface quite smooth and regular. An ideal tension fracture.

3 B 7	90 per cent through cast iron. Weld metal rather fibrous
3 B 1	80 per cent through cast iron. Fine granular spot between cast iron and weld metal
3 B 5	50 per cent through cast iron. 50 per cent through weld
9 B 1	40 per cent through cast iron. Remainder dark bluish metal like slag
9 B 3	90 per cent through cast iron. Balance weld metal as before. Double fracture. Second fracture 50 per cent complete nearly along line of weld
4 G 3	90 per cent through cast iron
4 G 5	Uneven break 50 per cent through cast iron. 50 per cent through weld metal. Alternating layers of light and dark metal
4 G 7	90 per cent through cast iron similar to specimen 9 B 3

GROUP 5

Break occurred along the line of weld junction showing various degrees of amalgamation.

4 B 4	Pitted surface showing series of warts like bottom of cat's paw. Irregular
6 B 1	Blotched appearance with very uneven surface
10 B 4	Pitted surface but of lesser degree than 4 B 4. Colors of metal darker
6 B 3	Blotched dark gray and light gray. Slag ball pulled out of weld metal size of pea
4 B 1	Blotched appearance but somewhat smoother than 4 B 4
9 G 7	Similar to 4 B 4. Large slag inclusion size of pea
4 B 7	Pitted surface. Series of cold spots like a cat's paw. Evidently poor amalgamation
2 G 4	Irregular surface. Cast iron pulled away to some extent
9 G 1	Pockmarked surface, somewhat smoother than 4 B 4 and 4 B 7
6 B 4	Somewhat smoother than 4 B 4 and 4 B 7
10 B 7	Same as 4 B 7
1 G 5	Same as 4 B 7
1 G 3	Same as 4 B 7
2 G 1	Quite smooth surface. Somewhat pockmarked. Some light crystalline sections overlaid by a scum of olive drab color
4 B 3	Blotched appearance. Light gray, fine grained areas intermingled with dark blue and olive drab. Insufficient fusion

TABLE VIII (Continued)

BROKE THROUGH THREADS ON FIRST TWO TESTS

These specimens broke in the threads on two tests with the results as given previously. The third time, the bars were turned down to ½ inch diameter over the welded section and tested. The fractures are as described.

THIRD TEST

3 B 3	Same as Group 4. 20 per cent cast iron shows. Balance is filler metal which shows a large dark area about 40 per cent of the entire surface. This is evidently a slag inclusion
3 B 4	Same as Group 4. Through cast iron at end of filler metal. Ideal tension fracture
9 B 4	Similar to 9 B 3, Group 4. Fracture through cast iron at end of weld, about 2 per cent of weld metal showing. Second fracture 10 per cent complete across cast iron
4 G 4	Similar to 9 B 3, Group 4. Fracture through cast iron at end of weld, about 5 per cent weld metal showing. Second fracture about 75 per cent complete, 20 per cent through cast iron. Balance along line of weld and then 20 per cent held by filler metal

will show that electrodes No. 4, 5, and 9 acted the best and electrodes No. 3 and 6 acted the worst. The time of welding and amount of electrode material used are noted in Table IV.

After the welding operation had been completed the welds were allowed to cool over night in the clamps to prevent any distortion in the cooling.

While cutting the plates into strips preparatory to turning the strips into standard test bars the machinist made the comments recorded in Table V. It should be noted that the G plates welded with electrodes No. 6 and 9 cut the easiest, with No. 5 next. As to the B plates those welded with electrodes No. 3, 6, and 9, and the plate welded with electrode No. 1 but by Method No. 2 cut the easiest, the two next in order being those welded with electrodes No. 1 and 5.

While turning these bars into test specimens with the lathe, the machinist attempted to classify the bars according to their machineability. The results are recorded in the three charts in Figs. 9, 10, and 11.

Tables VI and VII give the results of the tensile strength tests. *For the identifying numbers of the specimens see Fig. 4 and Table II.* Note that bars No. 2 and 6 of each plate are not recorded in Tables VI and VII. These bars are for hardness and microscopic tests which have not yet been completed.

All of the bars which broke while being machined fractured along the line of weld, except the hardest specimens 4 G 1, 5 G 7, and a soft specimen 8 G 4 which fractured nearly at right angles to the test piece. All of these specimens except the three mentioned showed a weakness which appeared to be due to poor amalgamation between filler metal and base metal. The fracture showed varying amounts of slag, burned metal, and chilled cast iron.

It will doubtless have been noticed that the majority of the tensile specimens listed in Tables VI and VII are approximately three fourths of an inch in diameter instead of one-half an inch as prescribed in the Committee Specifications. This change to a larger diameter was adopted by the Committee when it was found that several of the test bars were breaking in the lathe during the process of turning. The four bars 3 B 3, 3 B 4, 9 B 4, and 4 G 4 broke in the threads on two attempts to test them in the tension machine and were then turned down to approximately one-half inch in diameter across the weld section as shown in Fig. 12. These four bars were tested to fracture as shown in Fig. 13. The fractures are described in Table VIII and the grouping is illustrated in Fig. 14.

The tables giving the results of the Committee's tests are as follows:

Table I gives the chemical analysis of the grades of iron used.

Table II gives the electrode used with each plate welded.

Table III gives the observed characteristics of each electrode during the welding operation.

Table IV gives the data on the time required and the amount of metal consumed during the welding operation.

Table V gives the remarks on cutting the welded plates as made by the machinist.

Tables VI and VII give a résumé of the history of each test bar.

Table VIII gives the descriptions of the fractures of the test bars.

Table IX gives a brief summary of each welded plate grouped according to the electrode used.

CONCLUSIONS

From a consideration of the results of these tests, the Committee has reached the following conclusions:

> (1) That deposition of the filler metal to fill the weld V in a single spiral layer gives a softer but weaker weld than is afforded by depositing the filler metal in a series of parallel layers.

(2) That covering the surface of the cast iron with a layer of electrode material followed by a single spiral layer entirely filling the groove would be likely to give a weld having the desired characteristics.

(3) That the tests have shown electrodes No. 1, 4, 5, and 9 to give the best results for the B iron tests and electrodes No. 2 and 5 the best results for the G iron tests.

(4) That insofar as the variation of electrode strength and the personal equation of the operator may be neglected, these tests give an indication of the strength which may be expected from the various electrodes.

(9) That the readiness with which cast iron in general can be welded is more or less dependent upon the amount of free carbon present, i. e., the more free carbon there is in the cast iron, the harder that iron is to weld. In fact some cast iron welding jobs are not successful, and yet no account is taken of the character of the casting, but the welding process is blamed for the failure.

(10) That some so-called cast-iron castings are not really cast iron but rather badly burned iron which cannot be welded. Such jobs should not condemn the cast-iron welding process.

TABLE IX

PREPARATION OF TEST SPECIMENS

Plate	Electrode Used	WELDING		MACHINING		
		Time (Minutes)	Metal (Ounces)	Cutting (Hours)	Broke in Lathe Specimen Number See Tables VI & VII	Remarks Hardness
2B	6	30	28	3	3, 4 and 5	(S)
8G	6	32	27	3	3 and 4	(S)
5B	2	37	23.2	3¾	3, 4, 5 and 7	(MH)
2G	2	47	27.5	3½	3 and 7	(MH)
4G	2	52	24	5¾	1 (1st cut V.V.H.)	(H)
6B	1	41	25.8	3	5	(MH)
1G	1	40	22.2	4¼	4 and 7	(MH)
9B	1	39	23.4	3	None	(MH)
7B	9	30	20.7	3	3, 5 and 7	(MH)
9G	9	33	22.9	3	3, 4 and 5	(MH)
3B	9	35	23.8	8⅔	None	(VH)
4B	5	52½	23.0	3¼	5	(MH)
5G	5	46	21	3¾	7	(MH)
10B	4	40	23.3	7	1	(H)
8B	3	41	30	3	3, 4 and 5	(H.S.) Hardspots

(5) That while the Committee was satisfied with the specifications as drafted, there are several changes which it now feels should be made before other tests are undertaken along these lines.

(6) That in the arc welding of cast iron a short, steady arc, not over ⅛ inch in length, is essential.

(7) That in order to decrease the importance of the personal variable the automatic arc welding machine might be used.

(8) That the grades of cast iron used by the Committee can be welded, provided reasonable care is exercised in selecting the proper electrode material which is necessary depending upon the amount of free carbon present. The operator must have had experience sufficient to enable him to control his arc properly.

(11) That these tests are insufficient in number to be considered as a finished research, but that they are suggestive of further lines of investigation.

(12) That the standard test bar for cast iron should be larger than that prescribed by the American Bureau of Welding, i. e., the Welding Standard for brittle materials should be similar to the test bar recognized by the American Society for Testing Materials.

This test specimen might be lengthened for welding test specimens for the purpose of a clear section to be turned across the weld.

During the process of the investigations, the Committee has formulated several questions which, as yet, have not been satisfactorily and conclusively answered. An attempt has been made to outline a program of research and the solution of each point has an important bearing on the final conclusions.

(a) What is the correct method of depositing the filler metal to secure a machineable weld with maximum strength?

(b) Will preheating the welding surface with a carbon arc help in binding the filler and base metals?

(c) What current is best for obtaining the strongest adhesion between filler and base metals?

(d) Does the phosphor-bronze electrode offer any advantages as an antidote for the hard zone?

(e) What advantages are offered by the use of a nickel electrode?

(f) Does brushing the surface of each layer with a wire brush strengthen the weld?

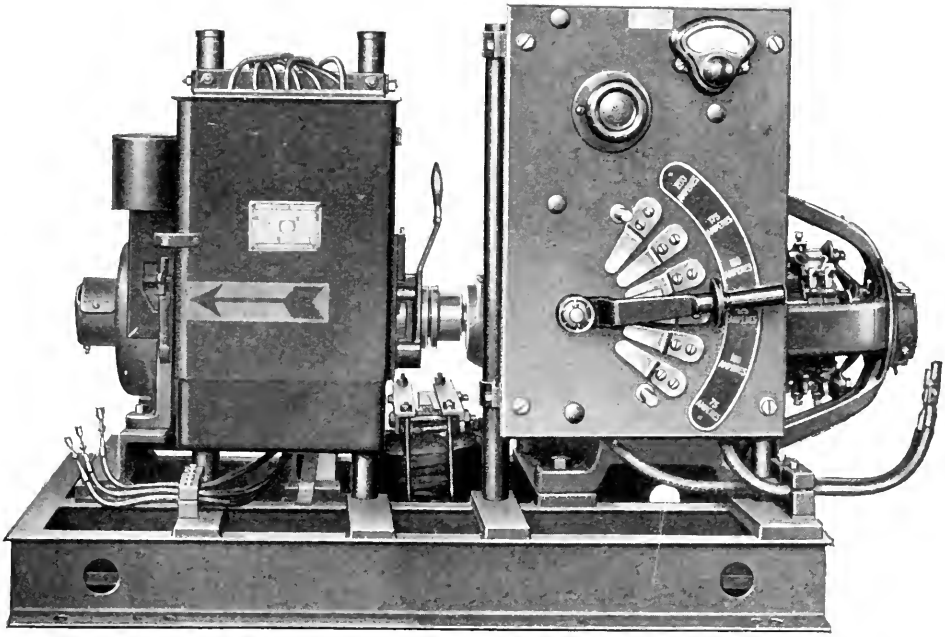
(g) How much is the hardness dependant on the speed of cooling?

(h) Will silicon soften the filler metal in the weld?

(i) Will hammering each layer of deposited metal while welding increase the strength of the weld?

(j) What is the best way to apply the filler metal to secure the maximum strength, requisite softness, and minimum contraction?

(k) What kind of electrode and what method of welding contribute to least porosity?



Single-operator Direct-current Arc-welding Apparatus for General Use with Alternating-current Supply

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted, which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Arc Welding

Arc Welding of Steel Structures. McKibben, F. P.
Am. Weld. Soc. Jour., Feb., 1923; v. 2, pp. 24-52.
(Lengthy illustrated paper showing numerous applications of electric welding. Includes reference to some welding methods and projects.)

Electric Arc Welding Apparatus and Equipment. Caldwell, J.
I.E.E. Jour., Feb., 1923; v. 61, pp. 253-277.
(Physical features of the iron arc as used for welding ferrous metals. Includes bibliography of 50 entries.)

Cascade Control

Operation of Induction Motors in Cascade. Cotton, H.
I.E.E. Jour., Feb., 1923; v. 61, pp. 284-293.
(Theoretical paper.)

Electric Distribution, Underground

Possibilities of Transmission by Underground Cables at 100,000 to 150,000 Volts. Taylor, A. M.
I.E.E. Jour., Feb., 1923; v. 61, pp. 220-252.
(Extensive paper on design. Includes bibliography of 19 entries.)

Electric Motors—Speed Control

Control of the Speed and Power-factor of Induction Motors. Walker, Miles.
Elec'n, Mar. 2, 1923; v. 90, pp. 216-219.
(Serial.)

Electrical Machinery—Parallel Operation

Operating Alternating-current Generators in Parallel. Brown, Ralph.
Power, Mar. 20, 1923; v. 57, pp. 435-437.
(Practical considerations.)

Insulating Oils

Maintaining Dielectric Strength of Transformer Oil.
Elec. Rwy. Jour., Mar. 17, 1923; v. 61, pp. 471-473.
(Describes centrifugal separator equipment for dehydration. Same, condensed, in *Elec. Wld.*, Mar. 24, 1923, pp. 698-699.)

Metals—Testing

Testing of Materials Used in the Manufacture of Electrical Equipment. Dawson, C.
I.E.E. Jour., Dec., 1922; v. 61, pp. 59-64.

Nozzles

First Report of the Steam-Nozzles Research Committee.
I.M.E. Proc., Jan., 1923; pp. 1-22.
(Report of tests and investigations conducted by a committee of the I.M.E. Includes numerous foot-note references to other articles on steam nozzles.)

Power-Factor

Improvement of Power-Factor. Kapp, Gisbert.
I.E.E. Jour., Jan., 1923; v. 61, pp. 89-135.
(With the discussion forms an extensive paper of theoretical nature.)

Relays

New Radial Relay Protection. Ackerman, P.
Elec. Wld., Mar. 17, 1923; v. 81, pp. 619-623.
(Excess-current relays with current, time and voltage elements to insure selective operation on radial transmission systems.)

Statistics—Electric Railroads

Statistical Data on Electrified Railroads. Bearce, W. D.
Elec. Trac., Mar., 1923; v. 19, pp. 113-116.
(Tabulated and other data on comparative costs of operation of steam and electric railroads.)

Thermometers and Thermometry

How to Use Mercury-in-Glass Thermometers. De Baufre, Wm. L.
Power, Mar. 20, 1923; v. 57, pp. 440-443.
(Suggestions for their use in power plant work.)

Vibrations

Production of Noise and Vibration by Certain Squirrel-Cage Induction Motors. Chapman, F. T.
I.E.E. Jour., Dec., 1922; v. 61, pp. 39-48.
(Mathematical study of causes and remedies.)

Vibration in Small Direct-Connected Units. Phillips, H. M.
Power, Mar. 13, 1923; v. 57, pp. 398-400.
(Discusses the subject mainly from the standpoint of correct balancing.)

NEW BOOKS

Construction and Exploitation des Grandes Réseaux de Transport d'Energie Electrique a Trés Haute Tension. Proceedings of the International Conference, Paris, 1921. 1176 pp., 1922, Paris, l'Union des Syndicate de l'Electricité.

Diesel Engine. Orton, A. 111 pp., 1923, N. Y. Isaac Pitman & Sons. (Pitman's Technical Primers.)

Electricity in Agriculture. Allen, Arthur H. 117 pp., 1922, N. Y., Isaac Pitman & Sons. (Pitman's Technical Primers.)

Plastics and Molded Electrical Insulation. Hemming, Emile. 313 pp., 1923, N. Y., Chemical Catalog Co.

Practical Tests for the Electrical Laboratory. Johnson, C. H. and Earle, R. P. 347 pp., 1923, N. Y., D. Van Nostrand Co.

Principle of Relativity with Applications to Physical Science. Whitehead, A. N. 190 pp., 1922, Cambridge, University Press.

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE Editor, JOHN R. HEWETT Associate Editor, E. C. SANDERS

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Vol. XXVI, No. 6 JUNE, 1923

CONTENTS

Big Creek No. 1 Hydro-Electric Power Station of the Southern California Edison Company. Capacity 52,500 kv-a., Static head 2100. This station is of special interest at the present time as the Southern California Edison Company have just placed in service the first commercial transmission line to operate at 220,000 volts.

The view shown on our cover was taken from the dome of rock over 3000 ft. above the station. The hole in the rock through which the picture was taken can be discovered by careful observation.

GENERAL ELECTRIC
REVIEW

THE TREND OF PROGRESS

The *Electrical World* published a remarkable issue on January 6th of this year showing the progress of the electrical industry. They noted in that issue three milestones in the industry's history.

1. Fifty billion—50,000,000,000—kw-hr. generated and distributed in the year 1922.
2. One-billion-dollars—$1,000,000,000—energy sale during 1922.
3. Five billion dollars—$5,000,000,000—of capital invested in the electric light and power industry.

When the age of the electrical industry is considered, these figures stagger the imagination and it must be remembered that even these figures do not give any idea of the gross size of the industry.

The *Electrical World* shows in a very interesting diagrammatic form that the capitalization of the electrical industry reaches the vast total of thirteen billion one hundred million dollars—$13,100,000,000—divided as follows:

Light and Power.........	$5,100,000,000
Electric Railways........	5,000,000,000
Telephone and Telegraph.	2,000,000 000
Electric Manufacturing...	900,000,000
Electric Merchandising...	100,000,000
Total...........	$13,100,000,000

The capitalization of the electrical industry thus exceeds that of any other industry in the country with the single exception of the steam railways which are capitalized at $18,000,000,000.

We shall soon have to get used to figures of astronomical magnitude in comprehending our industry!

These figures are of more than passing interest—they establish beyond doubt the fact that the electrical industry is the greatest, or one of the greatest, economic assets of the country. To what extent this truth is realized is illustrated by the extraordinary fact that the country's demand for electrical energy is so great that the kw-hr. consumption in the United States doubles each five years! If we still keep the pace this means that we shall generate and distribute one hundred billion kw-hr. and probably sell two billion dollars worth of energy in the year 1928!

There seems to be no apparent reason why this pace should slacken because in spite of these enormous figures Switzerland, Canada and Norway still lead the United States in point of kw-hr. consumption per inhabitant. It is true that the total kw-hr. consumption in Switzerland, Canada and Norway combined amount to less than one-fifth of our consumption, but there is no reason why our needs per capita should be less than in any other country.

It is only by the most intelligent, constant and hard work that the engineer is enabled to keep abreast of the industry's needs.

In our present issue we publish a number of articles which show the trend of development in many phases of the industry and it is always well to remember that it is the constant work of the inventor and research engineer that is making our progress possible.

The successful operation of transmission lines at 220,000 volts will open up many new fields of development which were not economically feasible at lower voltages. An overall increase in efficiency in our steam power stations, which can be attained only by paying the most careful attention to every detail of design in the entire plant, brings other uses for electric energy into the field of practical applications. And so the story continues—each advance made in getting more out of the material used in the construction of electrical apparatus —and each invention that enables us to do for one dollar what was considered impossible at two dollars a few years ago—

leading us forward in this spectacular march of progress.

There are approximately 4000 industrial plants in the United States that each use more than ½ million kw-hr. of electrical energy per year and there are approximately 15 million h.p. of electric motors helping to carry our industrial load. Nearly 8 million of the 21 million houses in the United States are wired for electrical service. Every kw-hr. put into service in these directions is consolidating and extending the economic soundness of the country's position amongst the nations of the earth—and doing its share in shifting the burden of mechanical labor from human shoulders and placing it on the machine.

Every advance made in the generation, distribution and control of electric energy is enabling our industry the better to play its part in advancing our civilization. It is in this phase of the work that the engineering developments and the industrial research carried on by large industrial corporations of the country are playing such a useful and prominent part. We often feel that the country at large has little appreciation of the benefits they derive from this constant organized effort to create new, and better old, devices designed to convert more abundantly our natural resources to the useful service of man.

J. R. H.

CARRIER CURRENT

We publish in this issue an article by Mr. A. P. Austin on Carrier Current which describes the apparatus used and the method of operating this system of communication. Owing to the importance of this new means of communication we asked Mr. E. P. Edwards, the Manager of the Radio Department of the General Electric Company, to write some editorial comment on this article. His remarks are given below:

"The importance of communication between the various units of a power transmission system is appreciated fully only by those who are responsible for rendering service to the public through that system.

"Even the smaller systems recognize the practical necessity for rapid, accurate interchange of information. Communication is to a power company what the nervous system is to the human body. Electric light, particularly, is 'eyesight' to the public, therefore, unless the nervous system of the power company is in satisfactory working condition, the public suffers directly and immediately.

"These facts will be better realized by the layman when he learns that many of the financial losses, inconveniences and annoyances occasioned by a cessation of power could be appreciably minimized through adequate and infallible communication facilities.

"In its constant endeavor to serve the public through the power company, the engineers of the General Electric Company have devised a practical method of communication known as the 'Carrier Current' system, which can either supersede or supplement other methods now generally employed. From actual experience gained through practical operation, it has been conclusively demonstrated that 'Carrier Current' is at least as satisfactory as any other system of communication now in use on transmission systems.

"If the power company proposes to install only one means of communication, 'Carrier Current' should be given first consideration, combining, as it does, many of the advantages of other systems with only a few of their limitations.

"Fundamentally, the carrier system makes possible the superimposing of two currents of different frequencies on the same metallic circuit: one of these currents is that normally carried by the transmission line in supplying power and light to consumers; the other is that produced by the carrier current equipment and is used for communication purposes solely, conveying oral instructions and information to the listener with greater clarity and naturalness than is usually possible through means of older systems.

"As would be expected, the method of generating carrier power and the transfer of this power to the transmission system is decidedly different from the methods employed at commercial frequencies."

Central Station Developments

By C. W. Stone

Manager Lighting Department, General Electric Company

Mr. Stone points out the general trend of central station development up to the present time and deals briefly with a few future possibilities. He thinks that public utilities in the future may serve the public by the radio broadcasting of entertainments, etc. His article is concluded with some remarks on public utility investments and on "central control" for large power systems.—Editor.

The progress in the development of the central station for the generation and distribution of electrical energy has been so rapid that it is difficult to forecast the future.

There have been some very definite steps in the developments of today with which we are all familiar. I refer particularly to the building of power stations for generating alternating current, and placing these stations at points distant from the immediate load, all of which was made possible by the development of motor-generator sets, rotary converters, high voltage transformers, and switching devices. This method of operation has been so thoroughly developed that the writer feels that future developments will necessarily be confined to refinements in the apparatus used, if the systems are still operated in this manner.

The demand for power has been so great that the development of larger waterwheel-driven generators, and larger steam turbines and generators, has been very rapid. One marked result of such development is that power stations are located in places where water is available. This, of course, always applies to water powers, but it has fast become the determining factor in the location of large steam generating stations.

Electrical energy can be distributed from almost any point with very small losses. Coal can be delivered at almost any location. Water for condensing purposes, however, cannot be obtained for other than relatively small powers except in definite locations. This has resulted in the location of large power houses, in many cases, at long distances from where the power is used, and has brought about many long distance transmission circuits at high voltage with many inter-connections between the systems.

It would appear that in the next decade there will be more and more developments of this nature, and more inter-connections between large systems. Such methods of operation have called for the development of larger and larger transformers, steam turbines, and oil switches. The average size of transformer is about double what it was five years ago. This applies equally to large switching devices. Steam turbines of 30,000 kw. were comparatively rare five years ago, but today are more generally used than almost any of the smaller size machines. While the 30,000-kw. turbine was considered large five years ago, machines of 50,000 kw. are in operation and some that are even larger are now being constructed.

When the alternating-current system of distribution was first adopted, there was no definite standard of frequency. Many systems were installed at 125 cycles, and others at 133 cycles. Practically all of the systems employing these frequencies have disappeared. Compromise frequencies were adopted in some cases; hence we have still in operation many systems employing 25 cycles, a few isolated systems employing 40 cycles, a very few employing 33⅓ cycles, and one or two employing 50 cycles. However, 60-cycle frequency has grown in popularity to such an extent that at least 90 per cent of all systems in this country are now operated at this frequency. The standardization of 60-cycle frequency has been of great help to both the operating and the manufacturing company, but it has also been a distinct limitation in the development of apparatus, particularly generating apparatus.

The difficulty of making large high-speed turbine generators for 60 cycles has forced us to build generators of either six or four poles, whereas, if it were possible to use frequencies other than 60 cycles—preferably higher frequencies—it is probable that safer generators could be built at a considerable saving in cost.

There seems to be no possibility with the large developments which are already in operation to make any change in the frequency used for the generation and distribution of electrical power, unless some new scheme for generation and transmission of power is developed.

The possibilities of the development of mercury arc rectifiers, or some of the many other types of tubes, such as those developed for radio communication purposes, may be the solution of this problem. If suitable tubes were available direct current could be used for transmitting power over long distances, and with the tubes this direct current could be converted to alternating current at the frequency of the existing distribution service.

The fundamental part of this problem, of course, is the development of the tubes themselves. It is fortunate, however, for all of us, that, if such tubes are available, there will be almost no fundamental changes to be made in the existing transmission systems, as all of these systems could be operated with direct current at the existing voltages, with less chance of trouble on the transmission systems than is now the case with alternating current; and transmission systems will be capable of transmitting at least twice the power which is now transmitted with alternating currents with the same losses; in other words, a transmission system which is good today for 100,000 kw. will be capable of transmitting 200,000 kw. with no greater loss, if direct current is used, with greater safety, and with the resultant economies in the fixed charges.

From the data now available we think that large power distribution at voltages above 220,000 volts with alternating currents will not be undertaken for some time to come. The great danger in the use of potentials higher than 220,000 volts for large powers over long distances is, that we may reach a condition of instability which might become so great as to make such systems inoperative.

The high cost of water power development for generating electrical power when added to the cost of transmission over long distances, has brought about a condition where in many cases it is cheaper to generate power by steam and distribute it than to use water power. This situation reminds one of that suggested by Jules Verne when he describes two men, one working to produce a gun which would fire a projectile through any armor, and the other working to improve the armor to resist penetration by a projectile from any gun. The result was that first one, and then the other, was ahead.

If a tube such as that above referred to can be developed to operate successfully with large amounts of power, and power can be transmitted by means of direct current at high potentials, it would appear that the water powers would become more available, and be greater competitors of the steam plant. I anticipate, therefore, that within the next generation we shall see marked progress in the development of such tubes, with the consequent development of more and more water powers.

The success which has been achieved in the development of automatic operation of substations, and substation apparatus, would apparently indicate that automatic operation would be applied more generally, not only to substation apparatus, but to generating apparatus as well, particularly in water power developments. A number of such power houses have been put into operation in the last few years.

The developments in radio communication, particularly in broadcasting, have been of only minor importance to the central station up to this time. There are somewhat less than 600 broadcasting stations in this country, each one requiring from 500 to 1500 watts, or less than the flat-iron load of a comparatively small city. Although many storage batteries are in use in receiving apparatus, requiring charging at definite periods, the total energy required is so small as to be practically negligible.

It seems as if it would be possible for the public service companies as represented by the electrical generation and distribution companies to furnish to their consumers service similar to the present broadcasting by radio. A definite charge could be made, which would result in making available for entertainment and educational purposes better programs than can be given by any scheme of radio broadcasting which has yet been suggested. The possibilities in this direction seem to be so great that more and more people will become interested in this class of development, with the natural result that something will be brought out to make it possible for consumers to plug into any lamp socket with special apparatus, and listen to any kind of program they may select.

The use of electrical energy has become so general for practically all industry, it would appear that the demand for such power will continuously increase, thus resulting in stabilizing the entire industry.

I think it is generally considered that public utility investments are the most stable investments which we now have. This indicates two things; first, the industry is on sound foundations, and second, the properties themselves have been financed and managed with great foresight by those who have been responsible for their development.

The movement started several years ago for customer ownership of public utility properties has been of great value, not only to the industry itself, but to all other industries. Many people have invested in such securities who previously had never owned any securities whatever. They have thus been taught the value of money and the value of saving.

The development of the large central stations, and the many substations which have to be connected, has resulted in a very complex system, difficult to operate except from one central point. Hence we find that all large systems are now operated by means of a load dispatcher similar to the train dispatcher of the railroads, these load dispatchers having under their supervision the operation of all the stations of the system. As the stations become more complex, and more extended, the difficulties of operation of such systems become greater. The load dispatcher can do no more than to give by means of telephone or telegraph, orders which must be executed by others. In times of stress, when the communication lines are interrupted, there are bound to be interruptions in the service, and it will become more and more necessary to have the load dispatcher in a position where he can himself have control of the operation of all switches, stations, and substations. It would seem as if the problem of distant control of apparatus is one of the most pressing which we have before us.

The possibilities in the development of control by means of so called carrier current devices are great. It has been demonstrated that high frequencies can be super-imposed on the existing transmission circuits without in any way interfering in their operation, and such high frequencies can be used for operating the control devices of the systems.

Problems and Developments in the Control and Interconnection of Power Systems

By H. R. Summerhayes

Engineer Lighting Department, General Electric Company

The author describes the problems which have to be met and solved when large power centers are tied together into superpower zones. He discusses the general problem as a whole and considers the control of huge volumes of power under both normal and abnormal conditions. He then deals with some of the more important factors essential to a solution of the problems met.—Editor.

The rapid growth of the large city systems with their huge generating stations, the extension of the power transmission lines of the country and their interconnection into networks, and the increase of voltage which has made it practicable to develop remote sources of hydro-electric power and connect them with existing markets for power, have made prophetic observers predict the establishment of superpower systems in various districts of the North American continent and the ultimate connection of these zones into one grand system.

While there are some parts of the country, notably the Pacific Coast and the Southeastern States, where such predictions have been nearly realized, their fulfillment in other districts has been delayed by less favorable conditions and awaits the urge of economic necessity.

In the meantime there are engineering problems to be solved. In the important industrial districts the interconnection of already large sources of power and the addition of new sources may cause a concentration of power, in case of short-circuit, beyond the capacity of existing protective devices. Operating and load despatching methods must be studied in the light of experience and revised to meet new conditions; the requirements imposed on generating, transforming and switching apparatus must be understood and compared with the limitations of such apparatus.

The designs must be changed where necessary and new apparatus designed and developed to meet the new requirements.

Protective systems must be analyzed and compared, limitations of protective apparatus investigated, and new protective methods and devices invented.

Characteristics of overhead transmission lines at high voltage and of great length must be determined, since our engineers will have to deal with trunk lines carrying large amounts of power for very long distances. Preliminary studies in this field indicate that in some projects in the near future, involving the transmission of power in large amounts to distances of four or five hundred miles, there are problems calling for new methods of treatment.

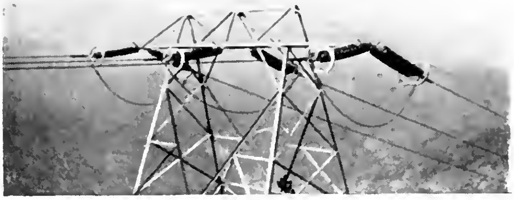

Fig. 1. Top of 220-kv. Strain Tower

In order to connect the urban power centers with each other and with the interstate transmission systems, underground transmission at higher and higher voltage will be required. Intensive development along these lines is already going on.

Finally, the engineers concerned in this work must keep in touch with new developments in electrical science, such as communication or remote control by radio or carrier currents, the possible uses of power tubes, the phenomena of corona, action of the electrostatic field, etc.

The General Problem

The general problem is to construct a network extending to all power and light users in the district, which shall act as a reservoir of power, from which electric power may be drawn when and as required, at any point in the district, and the power supply must be of the utmost reliability.

It differs from an hydraulic problem, however, in that it is not possible to store electricity as water can be stored in a reservoir. To store electrical energy, it must be transposed into some other form, as the chemical energy in a storage battery or the mechanical energy of water raised to a reservoir by electrically driven pumps. In actual practice, energy stored to meet the varying demand of an electrical power system is stored in some other form ready to be converted into electricity, as in a coal pile, in the heat energy in the water in a steam boiler, in the potential energy of water in forebay and reservoir.

In an electrical network supplied by a number of steam and hydroelectric plants the variations in demand may be classified as short time and long time. Momentary increases in power demand, within the overload capacity of generators running, are met by the immediate conversion of energy stored in boilers and forebay into electricity. Longer time power demands must be met by starting up more generating units, firing more boilers, etc., thus introducing a time element.

In systems employing a number of generating stations widely separated, it is the natural and logical practice to meet a local demand by supplying the power from the nearest generating station, or stations, since that involves the least loss in transmission; this policy may be modified by the presence of more efficient generating sources at a distance, or by the requirement of storing at one point and using available stream flow at another point.

On a large system with many generating stations widely separated it is obvious that the control of the system by one load despatcher must produce the best results, and that such control requires a system of communication as reliable as the transmission system itself.

The telephone communication on some systems has already been supplemented by the use of radio and carrier current. It seems quite possible that in the near future radio and carrier current methods will become the main reliance for the load despatcher with the telephone used as an auxiliary. It is not the purpose of this article, however, to consider the means of communication used.

The control of such a system may be considered under two heads:

Control under normal conditions.
Control under abnormal conditions.

In the present state of the art, and for several years to come, such a system will usually consist of:

(A) Steam electric generating stations in large cities and towns.

(B) Steam electric generating stations located for cheap fuel and ample condensing water, at a distance from centers of population.

(C) Hydro-electric generating stations.

(D) Trunk or feeder transmission lines connecting the important generating stations with the important distributing centers and with each other, at 220 kilovolts.

(E) Main transmission system, at 110 kilovolts or 66 kilovolts, radiating from the distributing centers, and interconnected into a network.

(F) Distribution lines at various voltages from 33 kv. down to 2300 volts.

(G) Substations on Class D, E, and F lines.

CONTROL UNDER NORMAL CONDITIONS

Load Control and Interchange of Power

When a single generating station is supplying power to a load at the terminus of a single line, the conditions are quite simple, the line drop may be readily calculated and the amount of power which can be carried by the line with a certain transmission loss and drop of voltage is easily obtained. When, however, two systems are tied together with the idea of exchanging power in either direction, the problem becomes somewhat more complicated. If a single tie line is used, or multiple lines passing over the same route, the amount of power transferred from one system to the other, the power may be regulated by adjustment of the governors on the prime movers of the two systems. The voltage at the various generating stations, however, may be fixed by local load conditions. The kilowatts transferred over the tie line depend on relative phase angle, which is obtained by adjustment of the governors, but the kv-a. and wattless component depend mainly on the relative voltage.

The sending stations must have a greater voltage than the receiving stations in order that the sending stations may carry the wattless component of the load as well as the watt component. Of course, this requirement may not always be necessary, as for instance, when the receiving station needs power but is short of water. In such a case one or more generators of the receiving station may be operated with just enough water passing through the wheels to take care of the losses and these generators may supply the wattless component. Steam generators are also run in the same way as synchronous condensers. There are cases, however, where due to breakdown of the generating equipment the receiving station needs to receive electricity in quantity and quality to carry all of its normal load, that is, it needs to get the wattless component as well as the watt component and at the proper voltage to supply its load. In such a case the sending station must supply the wattless as well as the watt component of the load, and if its voltage cannot be raised the voltage ratio must be varied somewhere along the line, usually in a bank of transformers, or by regulators, so as to force the wattless as well as the watt component over the line.

Fig. 2. Medium Capacity Synchronous Condenser, 8 poles, 1500 kv-a., 900 r.p.m., 4000-2300 volts

When power is to be exchanged in either direction, this requirement, which is often overlooked involves the provision of means for varying the voltage over quite a wide range. When station "A" is sending power and station "B" receiving power, the voltage at the "B" end of the line must be lower than at the "A" end and when station "B" is sending power and station "A" receiving power, the voltage at the "B" end must be higher. This applies for ordinary short distance transmission where it would not pay to put in large synchronous condenser capacity so as to transmit always at 100 per cent power-factor.

When two systems are tied together by two or more lines, which because of passing over different routes, or for other reasons, are of different reactance and resistance, and when the situation is complicated by the tapping off of load at intervals, still other means of regulation must be provided, since in this case it is necessary to see that each line carries its proper share of the load. For one line a greater difference in phase angle may be required than for the other line to make it take its proper share of the load. The total load exchange between the two systems is fixed by the adjustment of governors at the station, that is to say, by the average difference of phase angle which exists between the stations on one system and that on the other; the relative amounts passing over each line are determined mainly by the relative impedances of the lines and chiefly by the reactance. In order to make each line justify its investment by carrying its proper share of the load and of the wattless current, it is necessary to have means of controlling the phase angle and the voltage of the two or more lines independently, so that power may pass in either direction, properly divided over the two lines; also, the wattless component should be properly divided.

In order to accomplish the proper distribution of power, current and voltage, several methods are available. The proper use of these methods will depend upon the conditions of the problem, that is to say, the amount of power to be transmitted, differences in voltage and phase angle, line drop voltage, etc. For instance, if the tie is a long distance transmission line, involving a large line investment, it may be necessary for economical reasons to transmit power at 100 per cent power-factor, in which case large synchronous condenser capacity would have to be installed at both ends of the line to take care of the wattless component of the load, since either end may be the receiving end. If, however, the tie is a relatively short line, but possibly of high reactance drop, because of the presence of transformers, reactors, etc., the installation of large synchronous condensers at both ends may not be justified and the situation would be more economically taken care of by the use of regulators, or a wide range of voltage obtained by taps on the transformers.

Single Line Voltage Control

When the tie between load centers consists of a single line, there is only the voltage problem to be considered and this may be taken care of by taps on the transformers, synchronous boosters or single-phase induction regulators. The single-phase regulators give a boost or buck of voltage in phase with the applied e.m.f. and are usually cheaper than synchronous boosters. They are also more desirable for other reasons, notably that the regulator is not a continuously running machine, will stand heavier short circuit currents and can be designed for outdoor service.

For high voltages the regulator becomes somewhat cumbersome, since it is limited in voltage by its construction and must, therefore, be supplemented by series and shunt transformers to translate the efforts of the regulator into terms which can be understood by the high voltage circuit. For circuits of large power and voltage, therefore, it seems probable that the regulator will be often supplanted by some form of tap changing device on transformers. It is probable that on most existing tie lines between systems not enough attention has been give to the variation of voltage required by the interchange of power in either direction, and there are many places where this interchange over existing tie lines would be greatly facilitated if proper range of voltage ratio had been provided in the transformers, or if some voltage changing device could be added.

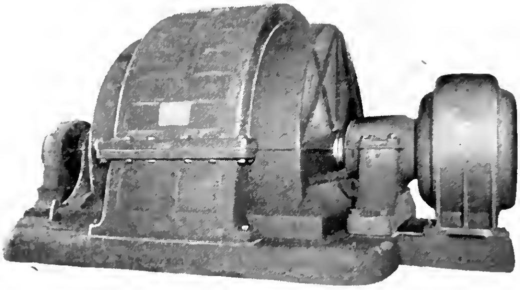

Fig. 3. Large Capacity Synchronous Condenser (12 poles, 25,000 kv-a., 600 r.p.m., 11,000 volts) with Connected Exciter and Induction Motor for Starting and Line Charging Purposes

Multiple Lines Voltage and Phase Angle Control

Coming now to the case where two systems are connected by multiple lines of different reactance and resistance, we have both the problem of proper change of voltage ratio for power in either direction and proper change of phase angle and voltage ratio relatively between the two lines. One solution would be to employ single-phase voltage regulators to take care of the voltage differences in either direction and three-phase regulators to take care of the phase angle. Another method would be the use of synchronous boosters with motor-driven devices for adjusting the stator angles. Probably the prettiest solution consists of two three-phase regulators in series in one of the lines, or the equivalent of one three-phase regulator in each tie line. This arrangement permits the relative adjustment of both voltage and phase angle through a very wide range.

Fig. 4. Large Induction Voltage Regulator of the Water-cooled Outdoor Type

Here again, however, the regulator becomes somewhat cumbersome and expensive when applied to high-voltage systems, on account of the necessary series and shunt transformers and we come again to a transformer tap changing method as the cheapest arrangement, although possibly not quite so convenient in operation as the regulators. By suitable combinations of two transformer windings per phase and two sets of taps, it is possible to adjust both voltage and phase angle independently and thus meet the requirements of parallel tie lines of different voltage and reactance to divide the load properly.

Having provided a suitable range in the transformers to take care of voltage adjustments, so as to allow for exchange of power in either direction and for different voltages on parallel lines and having provided suitable combinations of transformer windings to obtain the phase angles required for division of load between lines, we come to consideration of how the transformer taps should be changed. If the load can be thrown off the line while the change is being made. the matter is simple. Only ratio adjusters are needed. In usual practice, however, and in order to maintain the best condition, it is desirable to have the voltage follow changes in load and consequently the most convenient operating arrangement will be one permitting the changing of taps without interrupting the load. There are several methods of doing this, which are applicable under various conditions. It is impossible to say that one method is the best for all conditions. An arrangement suitable for one set of conditions, such as voltage, current, number of taps, frequency of change desired, would not be the cheapest under other conditions. All of these methods, however, are usually cheaper than regulators, but operate in much coarser steps and are not capable of such fine adjustment. Some of these arrangements are as follows:

First. A transformer may be provided with parallel windings, that is to say, two windings for each phase, with switches arranged so that half of these windings may be cut out, throwing the load on the other half while the taps are being changed. The changed winding is then cut into service in parallel with the other, which is in turn cut out and changed. This method is well adapted to circuits of large power, since on a large transformer the windings may frequently be in multiple anyway, or that provision of multiple windings does not mean a great increase in expense. The taps, however, always mean additional expense. It is obvious that while one winding is cut out the other winding must carry the entire load, that is to say, double rating of the winding for a short time, but this is not a great objection. It is apparent that after one winding has had its taps changed and is thrown into parallel with the other winding not changed, there will be a circulating current, but this condition is also temporary and means that the steps must not be too far apart. It is perfectly practicable to make a 5 per cent change on all ordinary transformers of the usual reactance. The switching and tap changing devices should be properly controlled and interlocked for safety and convenience of operation, all three phases being operated at one time.

Second. If one winding of a transformer bank is delta connected, instead of using double windings it may be simpler to install switches to open consecutively each side of the delta, leaving the line tied to the remaining two sides of the triangle in open delta. While each side of the delta is open, its taps are changed by the ratio adjuster.

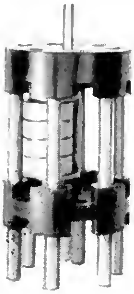
Fig. 5-a. Drum Type Ratio Adjuster Mechanism

Third. The taps of each winding of a transformer bank may be brought out to an insulated switch which operates to change the taps without interrupting the load flowing through the transformer bank. In order to do this, it is necessary while changing taps to short circuit a portion of the transformer winding through a reactor, resistor or auto-transformer. There are quite a variety of schemes of this general nature varying in details. For instance, under certain conditions of current and voltage the switching from tap to tap may be done in air. Under other conditions, under oil. The switching may be done by a drum controller, hand or motor operated, or by contactors operated electrically or from a cam shaft. A few of these schemes have been worked out and some are in actual operation.

Referring to any one of the above three general methods of changing taps, the extra complication in cost involved will usually be found to be well justified by the increased availability of the large tie line investment to carry its proper load and current in either direction and under all conditions.

The use of such devices is independent of the use of synchronous condensers, which may, however, be used to accomplish the same purpose, although put in for other reasons. It is quite possible that in many cases a combination of such voltage changing devices and synchronous condensers will be found advisable.

Another method of causing the load to divide properly in two parallel lines of unequal impedance is that suggested by Mr. John C. Parker of the Brooklyn Edison Company, which employs two series transformers, one in each line, with their secondary windings connected in multiple. Each series transformer is of a size approximately equal to the line current multiplied by half the difference in impedance volts between the two lines. This arrangement functions entirely automatically, but must be short circuited when one line goes out of service. It can be extended to any number of parallel lines.


Fig. 5-b. Dial Type Ratio Adjuster Mechanism

Automatic Generating Stations and Substations

In a large power system, containing a number of hydro-electric and steam stations, the diversity of power demand and the large steam reserve will permit the installation on low head streams, where effective water storage would not pay, of hydro-electric plants using a large proportion of the maximum stream flow.

For such plants full automatic operation, or automatic operation supplemented by remote control will be particularly attractive, since a generating station whose output follows the steam flow will operate at partial loads for long periods, and it is desirable to keep the cost of attendance as low as possible.

In the full automatic station the starting and stopping, connecting in and disconnecting, load control, voltage control and protection are entirely automatic; the number of machines in service is usually controlled by variations in the water level.

When remote control is added it may be used merely to determine the number of machines in service; but if desired may be extended to cover all the automatic functions except protection, and to include switching of lines.

During 1922, a 5000-kv-a., 6600-volt hydroelectric generating unit under full automatic control by a time clock or float switch was placed in operation by the New England Power Company.

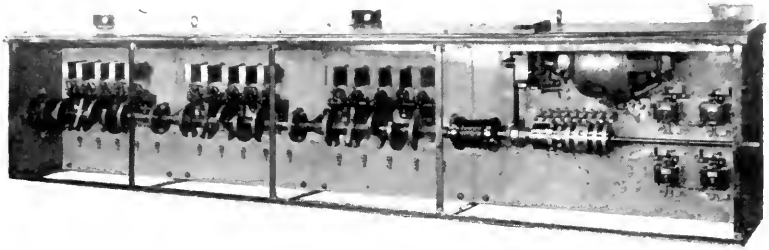

Fig. 6. Cam Type Tap Changing Switch for 525-kv-a. Three-phase, 7000/12,000/445-volt Transformer

A remote control unit of 11,750 kv-a., 13,200 volts was installed on the system of the Washington Water Power Company.

Devices familiar in automatic telephone and printing telegraph service have been applied to remote station control, utilizing not over four pilot wires, which serve also to bring back indications of the operation of devices in the controlled station.

An application of this method has been made in two of the a-c. switching stations of the Eastern Massachusetts Electric Company. It is well adapted to the control of unattended switching or sectionalizing stations on transmission lines, as well as to stations containing running machinery.

The near future will, no doubt, see carrier current methods applied to similar work.

A notable installation of automatic substations has been made for the Kansas City Power and Light Company where the entire Edison system of 15,000 kw. will be supplied from five automatic stations, each containing two 60-cycle synchronous converters.

Frequency Changers

In the interconnection of power systems there will be some cases where difference in frequency must be taken into account. In New York State, for instance, nearly 70 per cent of the power generated is at 25 cycles and somewhat less than 30 per cent at 60 cycles, the remainder being mostly at 40 cycles. It is, of course, expected by engineers that the main super-power stations for this vicinity, as well as for the rest of the country, must be at 60 cycles and a great deal of the future extension of the present 25-cycle systems may be at 60 cycles. The standard European frequency (50 cycles) is in use in Southern California, 30 cycles in parts of Michigan, 40 cycles in the vicinity of Albany, Schenectady and Troy, with some isolated cases elsewhere. There are a few instances where in order to obtain a slight advantage in the cost of frequency changers $62\frac{1}{2}$ cycles has been adopted, so as to get frequency changers of 375 and 750 r.p.m., instead of 300 r.p.m., which is the highest speed available for 60 to 25 cycles transformation. The great bulk of frequency changers in use are of the synchronous type, that is to say, synchronous machines on both ends. In this type when used to tie two systems together the maximum kilowatts transmitted must go through the shaft and is equal to the maximum kilowatt output of the generator. A short circuit on one system, involving a heavy output of reactive kv-a., from that end of the frequency changer may not draw very much power from the other system, since the current to a short circuit is largely reactive and the torque on the machine and output of the motor may be less than full load. This is an advantage in one respect, since a short circuit on one system does not pull down the voltage on the other but becomes a disadvantage when synchronous converters supplied from both systems are operating in parallel in the same substation. In this case it is desirable to have the voltages of both systems droop.

The cascade form of frequency converter, consisting of a synchronous machine of 25 cycles, 300 r.p.m., coupled to a 60-cycle induction machine has been developed to meet the requirement of a tie between two systems, which will include the feature of direct transformation from one system to another. In this set the stator of the 25-cycle machine is connected usually through a transformer to the collector rings of the rotor of the 60-cycle induction machine having fourteen poles. Twenty-five cycles flow through the rotor and 35 cycles is added by rotation, producing 60 cycles in the stator. The 25-cycle machine provides excitation for the 60-cycle induction machine, which operates at 100 per cent power-factor as far as the 60-cycle system is concerned It is even possible to over-excite, so as to have the 25-cycle machine compensate for poor power-factor of the 60-cycle system, and if it were not for the fact that the induction machine has to be made larger to carry these wattless currents, there would be some advantage in doing this, since 25 wattless kv-a., produced in the 25-cycle machine will become 60 wattless kv-a., in the 60-cycle system.

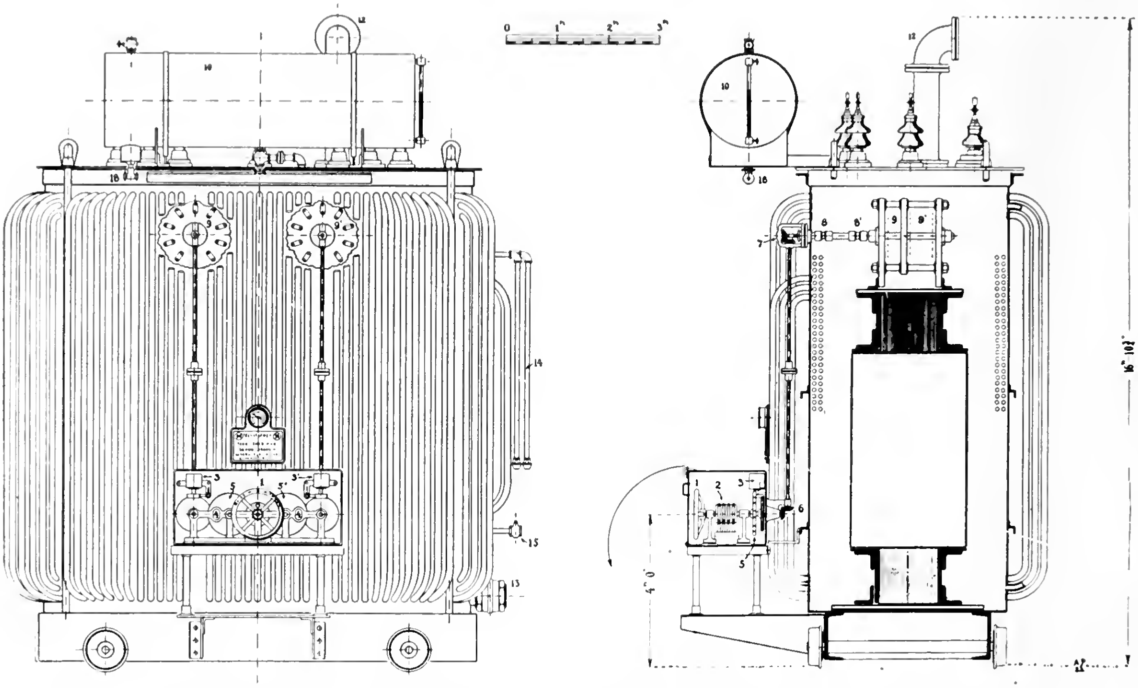

Fig. 7. Ratio Adjuster Type Tap Changing Mechanism for 20,000-kv-a., Three-phase, 44,000-volt Transformer with Parallel Windings. One revolution of handwheel changes taps one step on both windings, the load being carried by one winding while the other is being changed

For a tie between two systems of different frequencies, it is sometimes required to locate the frequency changer at a substation distant from generating stations of either system. To regulate the amount of power passing through a synchronous frequency changer would require constant communication between the frequency changer station and the various generating stations. This difficulty can be overcome by installing an inverted 25-cycle synchronous converter in series with a 60-cycle synchronous converter, but the induction set is probably a more stable combination, although there is not much difference in the cost and efficiency.

VOLTAGE AND POWER-FACTOR

Generator Regulators

In power stations in large cities supplying current to an alternating-current distributing system through a large number of feeders, with each feeder capacity relatively small compared to the kilowatt capacity of the generators, generator voltage regulators have been seldom used in the past.

On the other hand, in large hydro-electric generating stations, which usually supply power through a few transmission lines of large capacity relative to the capacity of the system, generator voltage regulators are in common use and are really required for good service on account of the large proportion of load which is lost if one line is lost. In a few of the large city stations where the load varies in large increments, for example Pittsburgh supplying a steel mill load, and Philadelphia a railroad electrification, generator voltage regulators have been found necessary. They will probably be more extensively used in the future in the large steam stations as interconnection with other systems takes place, since with the regulator the synchronizing power and stability of the system are improved.

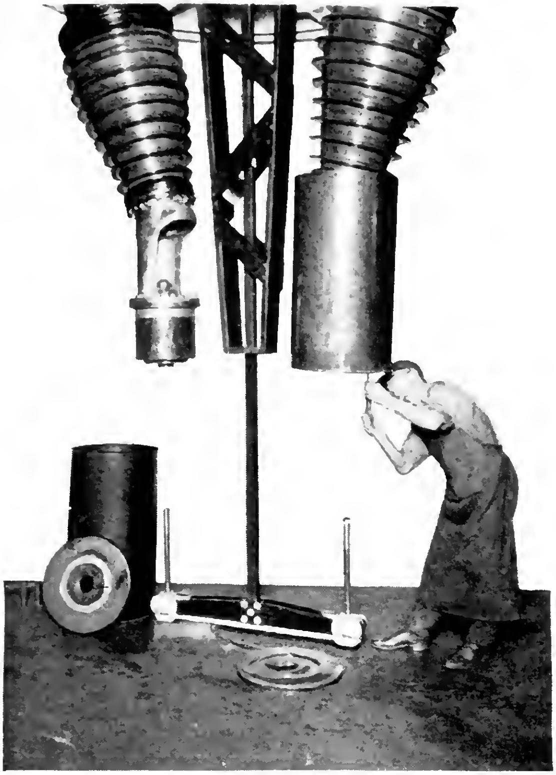

Fig. 8. Interior View of the 187,000-volt Oil Circuit Breaker, Tank Removed

Synchronous Condensers

Synchronous condensers are generally used for the control of power-factor and interlinked with this is the control of voltage at substations. On long high voltage transmission lines the line investment is so high that it must be utilized efficiently and a comparatively large investment in synchronous condensers is not only justified by this requirement but necessitated by the fact that without the synchronous condenser the voltage regulation would be so bad that the electricity at the receiving end would not be practically useful. On shorter lines, many companies are now getting away with rather poor voltage regulation and inefficient transmission, where it would not take very close figuring to show that the installation of synchronous condensers would be justified. In the case of a transmission network, a conception of the effect of synchronous condensers may be obtained by imagining a tarpaulin spread over a field and supported on various posts which are the generating stations, the canvas sagging to a lower level between the posts, representing lower voltage. At any point where the sagging is too much, another post may be put in by installing a synchronous condenser which boosts the voltage in that neighborhood. By regulating the field of the condenser, the voltage may be held constant with variation of load, that is to say, we have an adjustable post which we can raise up as more water falls on the tarpaulin.

It has been frequently suggested that synchronous boosters could be used to control the voltage of a system. While the synchronous booster may have some field when used in conjunction with a synchronous condenser, that is to say, where voltage control is more important than full power-factor control, the synchronous booster has never been able to compete when used alone with the induction regulator.

As explained in the paragraph under "Load Control" a wide range of transformer taps is necessary on transformers forming a tie between two systems where power is interchanged in either direction, in order that the power-factor of the load exchanged may be properly controlled.

CONTROL UNDER ABNORMAL CONDITIONS

Abnormal conditions may be considered under two headings:

Excessive currents.
Excessive voltages.

We are able to calculate quite closely the mechanical and thermal effects of excessive currents and are learning how to provide for them in our designs.

Excessive voltages, however, are not so well understood. They are more erratic in their appearance and effects and a great deal of investigation is necessary before we can be so sure of our factor of safety as we are against excessive currents.

Excessive Currents

The current existing in a short circuit is the voltage divided by the impedance, very easy to calculate in a simple circuit, exceedingly difficult to calculate in a network supplied from several sources of power. The difficulty of such a calculation has led to the use of calculating tables, in which the network with its generators, transformers, lines, etc., can be represented by resistances through which direct current is passed and a short circuit being made at any point, the currents flowing to the short circuit may be measured at all points desired. This method of calculation has proved so useful in studying power systems that no less than sixty important system studies were made on the calculating table of one manufacturer during the period of a year. Several of the large transmission systems, notably the New York Edison Company, Alabama Power Company, New England Power Company, have their own calculating tables.

To make a complete study of the flow of current, including power-factor, single-phase short circuit, etc., would require a much more complicated miniature system, in which three-phase lines could be used and reactance, resistance and capacitance introduced, but for the purposes of determining the proper size of switches and reactors and the setting of relays, most problems can be solved on the miniature system consisting of the direct-current calculating table.

Having determined the r.m.s. alternating current flowing at various points, the next step is to calculate the peak current on the first cycle, including the direct-current transient usually present on short circuits. This peak current determines the mechanical shock to the apparatus, which must be designed to stand such currents with suitable factor of safety. There have been many failures of electrical apparatus because it was not well understood that the mechanical strains depend on this peak current.

The designer must then take account of the thermal effects due to the short circuit. A very conservative rule would be to make apparatus connected in series with an underground cable so that it would stand without injury the same overloads of short duration as the cable itself, in case a circuit breaker fails to open immediately.

To apply this same rule to apparatus connected to overhead transmission lines may be beyond good judgment.

When it is realized that the mechanical effects in a large transformer may amount to many tons attraction between the windings, and that the thermal effects due to short circuit currents in circuit breakers have been known to injure the apparatus in less than half a second, the problem confronting the designer of apparatus connected to a large transmission system may be appreciated. The simple way to avoid these problems would be to segregate systems instead of interconnecting them, but the economics of the situation appear to demand interconnection. The engineer is then forced to use current limiting reactances to cut down the concentration of power at any one point.

Current limiting reactances have been widely used on systems below 15,000 volts and are now coming into use on systems of 25,000 volts. A few have been built for 60,000 volts. As the interconnection of power systems progresses, the current limiting reactors are likely to be widely used on high tension systems, although engineers have so far ingeniously avoided their use by careful placing of transformers, etc.

On a high tension system where the mechanical effects of the peak current on the first cycle may not be important, but where it is desired to limit the current in order to reduce rupturing capacity of circuit breakers, etc., there is available a device known as the saturated core reactor, which under normal conditions up to full load interposes only 10 per cent reactance, but at times of short circuit becomes 35 to 40 per cent. There will probably be a field for this in reducing the cost of high tension circuit breakers at important power centers.

Automatic Operation

On moderate voltage distribution systems, the use of automatic and remote control substations and of automatic reclosing switches in manual substations, has become quite common and such stations have proved their worth in service.

In the interconnection of large power systems operators will probably be required in the important switching centers, which may involve a large investment in switching apparatus and possibly in regulating apparatus; but automatic operation, such as automatic reclosing of switches, may soon be introduced in such stations.

In the recent development in oil circuit breakers, involving the elimination of oil throwing, the use of improved test facilities by the manufacturers and important service tests have enabled the designers to obtain more exact knowledge of the operation and basic principles of oil circuit breakers which are now being made safer and more certain in operation and with a better known factor of safety.

Oil circuit breakers have been built for rupturing capacity of one and a half million kw. To form a better picture of what this means call it two million horse power or 1100 million foot pounds per second.

Power may pass through the circuit breaker at this rate from the time the short circuit is established till it is interrupted, say, one-fifth of a second or 220 million foot pounds or enough power to lift 110 tons 1000 feet.

After the circuit breaker contacts part, however, the job is done quickly, one cycle on a 60-cycle circuit being a good time performance.

During this one sixtieth part of a second, there may be absorbed in the circuit breaker about one million foot pounds, enough to lift a ton 500 feet.

Relays

The general principle in the design of relay systems is to consider the component parts of the system in as small units as possible and arrange the system of relays so that an accident to any part of the system whether a piece of apparatus or a section of line, will, by the excessive currents flowing, isolate that part of the system without interrupting service on any other parts. This general principle is simple enough, but its application on a power network is often difficult and limited. Service interruptions have, however, been largely done away with by modern relay systems and by grounding the neutral. Grounding the neutral provides a determined flow of current to any fault and simplifies the task of the relay engineer.

Excessive Voltages

Excessive voltages at fundamental frequency in case of an accident at any point of the system are best prevented by the use of a vibrating regulator. Rheostatic regulators are usually too slow to take care of the sudden voltage rises when a large part of the load is thrown on.

Excessive voltages, due to transient sources, steep wave fronts, inductive effects from lightning, etc., are present on every system and are best taken care of at present by lightning arresters of the electrolytic, or other type, having a large discharge capacity and action within half cycle. Such voltages, however, may be present at various parts of the system, since lightning arresters cannot be located everywhere, and allowance for these voltages has had to be made in the design of apparatus from the experience of the designers. This matter has been mostly empirical and while a great deal of work has been done in the determination of such voltages, a great deal more remains to be done. This is a field towards which many investigators are directing their efforts. Practical experiments on systems during the next few years will result, we hope, in more exact knowledge, not only of the voltages which exist on systems, but their character, duration, and their effect on insulation.

Large Power Transformers

By W. S. Moody

Engineer, Transformer Department, Pittsfield Works, General Electric Company

The design and problems of transformers is of vital interest to all responsible for the transmission and distribution of electric power. Mr. Moody has had vast experience, over many years, in designing transformers and in this article he gives our readers data which will enable them to understand the manufacturer's problems as well as help operating engineers to a better understanding of the solution of their problems.—**Editor.**

Due to the constant and rapidly increasing demand for electrical energy, largely resulting from the great increase in the cost of coal, generating stations having very large outputs are being built. The use, therefore, of large units for the generation, transmission and distribution of this energy is necessary for the sake of economy, first, in the cost of the apparatus, second, in that the best operating efficiencies may be obtained, and third, in the number of units used.

In the case of the static transformer, which is such an indispensable part of the transmission and distribution equipment, the question of cost becomes more important as the voltage rating becomes higher. In a paper published in 1912, the writer pointed out that since the first attempts in 1892 to transmit power over any considerable distance, the art of transformer building had progressed commercially in voltage limits at a rate of approximately 10,000 volts per year. The writer then predicted that progress in that respect was likely to keep on at about the same rate. Fig. 1 shows the actual progress to date. It will be seen that the prediction has been well confirmed, except for lack of progress during much of the "World War" period. However, this temporary retardation, it should be noted, has been made up.

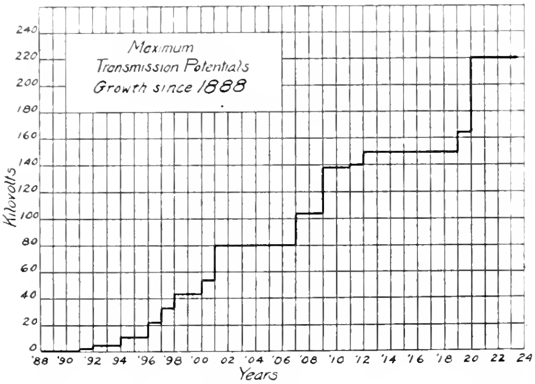

Fig. 1. Curve Showing Yearly Increase of Maximum Potential for which Power Transformers Have Been Built

There is a common misconception that when high voltages, capable of transmitting power economically over 250 to 500 miles, are used, every hamlet along the way can have electric power. The cost of transforming at such high voltages is far too great to make it commercial to supply small customers unless there are enough of them so situated that they can be collected into a unit of service on some much more moderate voltage. Often the demand is so scattered as to require three successive transformations before the individual user is reached.

Fig. 2 shows the relative cost per kv-a. of self-cooled transformers of different sizes designed for different voltages. The portion of the curve where the cost per kv-a. takes a

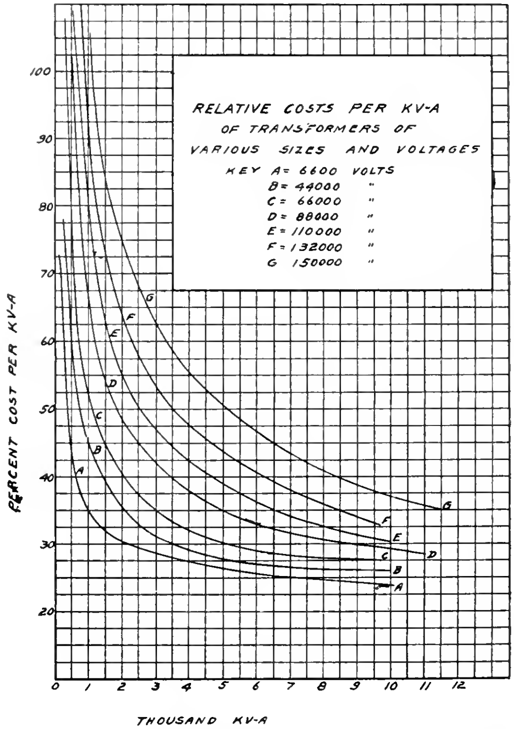

Fig. 2. Relative Costs per Kilovolt-ampere of Transformers of Various Sizes and Voltages

rapid upward turn indicates the minimum size below which it is not usually economical to go, and it will be noted that the higher the voltage the larger is the size at which this occurs. Thus, if for comparison, we compare the points where the curves have a 30 deg. slope upward, we find that this occurs at 1500 kv-a. on the 6600-volt line, 3000 kv-a. on the 44,000-volt line, 4500 kv-a. on the 88,000-volt line, and 7500 kv-a. on the 150,000-volt line. Small units must therefore be avoided by combining the demand at a lower voltage until there is sufficient to use the high voltage without excessive transformer cost.

The lowest economically permissible kv-a. limit becomes higher as the voltage increases because that vital and expensive part of a high-voltage transformer, namely, its insulation, is almost constant in cost regardless of size. The relative cost of the major insulations of 150,000-volt transformers is shown in Fig. 3 where, it is interesting to note, the cost of the insulation of a 1000-kv-a. transformer is as much as 50 per cent of that of a 10,000-kv-a. transformer. Fig. 4 gives the cost of insulation proper in per cent of the total cost of the transformer. Although these curves alone would be sufficient argument in themselves, there is the further fact to be considered that the insulation proper is only one part of the excess cost entailed by high voltages, and that the excess cost due to larger size of tank, core, coils, clamps and oil necessitated by larger clearances demanded for insulation are also chargeable against the cost of high voltage.

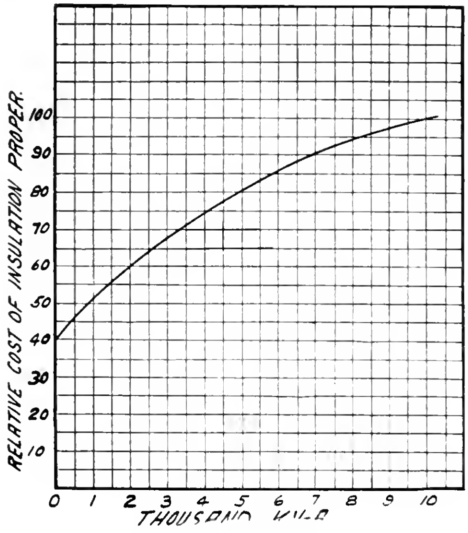

Fig. 3. Relative Cost of the Major Insulation of 150,000-volt Transformers in Per Cent of that of the 10,000-kv-a. Unit

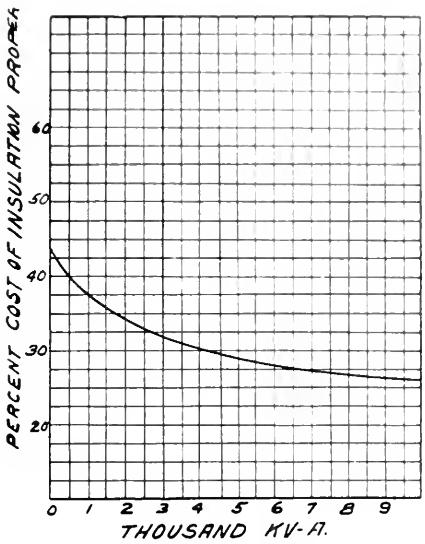

Fig. 4. Cost of Insulation Proper of 150,000-volt Transformers in Per Cent of Total Cost of Transformer

Since large (*i.e.*, power size) transformers have practically the lowest cost at 6600 volts, we will take the cost of the 6600-volt self-cooled line as a basis and show in Fig. 5 the excess cost of 150,000 volts in various kv-a. sizes expressed in per cent of the cost of the

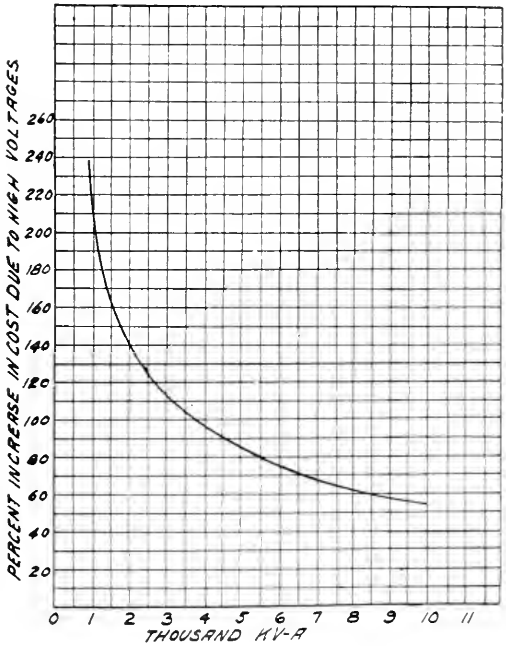

Fig. 5. Excess Cost of 150,000-volt Transformers Above that of 6600-volt Transformers in Per Cent of Cost of the Latter

corresponding 6600 volt unit. It is interesting to note that 150,000 volts costs about 55 per cent more at 10,000 kv-a., but about 220 per cent more at 1000 kv-a., and of course even higher at still smaller capacities.

Minimum sizes used on any voltage should therefore be well beyond the zone where the cost per kv-a. increases rapidly. Transformers for the highest operating voltages such as 220,000 volts should preferably be above 10,000 kv-a. per phase.

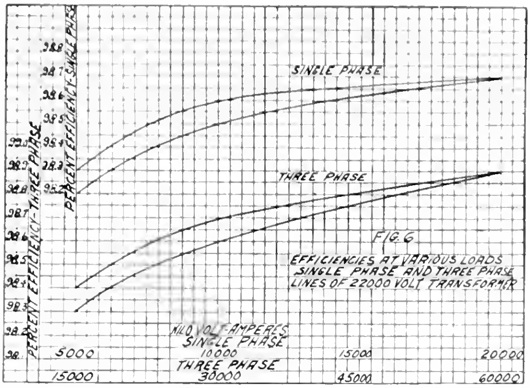

Fig. 6. Transformer Efficiencies at Various Loads. Single-phase and three-phase lines of 220,000-volt Transformers

Aside from the advantage in cost in favor of larger sizes there is also an advantage in efficiency in favor of the larger sizes as shown by the efficiency curves for a line of 220,000-volt transformers given in Fig. 6.

In the past few years there has been a more rapid growth in the size of self-cooled transformers than in water-cooled transformers. This is largely due to the development of economical and compact means of dissipating the heat from large self-cooled units.

The losses in the coils and core of a transformer vary approximately as the cube of the dimensions, while the radiating surfaces of the coils and core as well as the surface of the containing tank vary as the square of their respective dimensions. As the size of a transformer is increased, it is evident that a point is soon reached where it is necessary to provide additional surface on the tank by means of corrugations or other irregular outlines. The difficulty of obtaining sufficient surface, particularly on the tank, and still maintaining a strong mechanical structure was for years the principal factor in limiting the growth of large self-cooled transformers. This problem has now been satisfactorily solved by the use of tanks with external tubes where shipping clearance will permit or separable radiators when the dimensions are too great to permit shipping the complete unit. Self-cooled transformers of moderate voltage may be shipped completely assembled in their tanks, filled with oil, ready for installation in sizes up to about 5000 to 7500 kv-a. Larger and higher voltage transformers may require the removal of the radiators for shipment and extreme sizes may require that the transformers be removed from their tanks for shipment.

Fig. 7 shows the relative growth in size of self-cooled and water-cooled transformers for the period from 1906 to 1923. The curves were prepared from the records of transformers built by the General Electric Company, but it is believed that they are sufficiently representative to show the general record. It will be noted that up to 1907 the largest self-cooled transformer was 500 kv-a. while the largest water-cooled transformer was 7500 kv-a. or fifteen times as large. At the present time the largest self-cooled transformer is 15,000 kv-a. while the largest water-cooled transformer is 25,000 kv-a. or only 66 per cent larger. Self-cooled transformers can be built economically and compactly in even larger sizes when requirements make them desirable.

As both self-cooled and water-cooled transformers may now be built for any desired output, the operating engineer is afforded a free choice of either of the two types. There will be several factors affecting his choice. If water-cooled transformers are desired, there is required, for a large installation, quite a large supply of water sufficiently pure not to corrode or clog the cooling coils. The extra cost of the water and pumps, if required, must be considered, as well as the possibility of

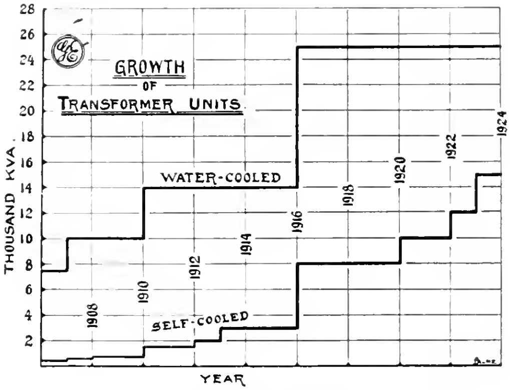

Fig. 7. Relative Growth in the Size of Self-cooled and Water-cooled Transformers

water freezing in an outdoor transformer in severe climates. A self-cooled transformer will occupy more floor or ground space and, if indoors, it may sometimes be difficult to provide proper ventilation. However, the self-cooled transformer will normally have higher efficiencies, while the water-cooled unit has the advantage in first cost. Fig. 8 gives the cost of water-cooled transformers expressed as a percentage of the cost of self-cooled transformers. This curve is intended to show merely the trend and should not be used to cover specific cases, as the difference will vary not only with the kv-a. rating but also with the voltage and other special requirements which may have to be fulfilled.

Having decided on the method of cooling, there are certain features which, while important to consider in the choice of any transformer, should be given special consideration when one is to purchase a large unit, and particularly in a unit designed for high voltage. The most important of these features are:

1st. The magnetic core should be rigid and capable of supporting not only itself but also the major insulation and windings against all possible abnormal stresses, as for instance, short circuit forces.

2nd. Windings should consist of cylindrical or disc coils, and for very high-voltage transformers they should be arranged concentrically, not interleaved.

3rd. Major insulations should furnish rigid support to windings and have ample strength to withstand stresses accompanying short circuits.

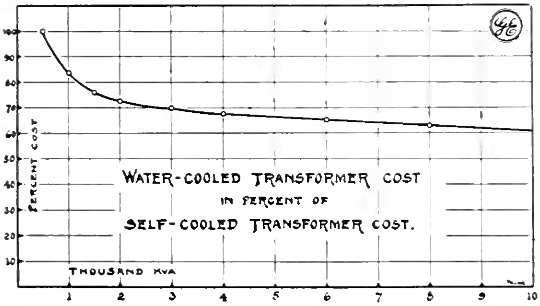

Fig. 8. Water-cooled Transformer Cost in Per Cent of Self-cooled Transformer Cost

4th. Taps should be avoided, but if they must be used, they should be located as far removed from the line connections as possible and so as not to cause any magnetic unbalancing.

5th. The tank construction should be very substantial and such as to exclude air.

The following discussion shows how these features are applied to standard General Electric practice:

First. The magnetic cores should be rigid and capable of supporting both major insulation and windings.

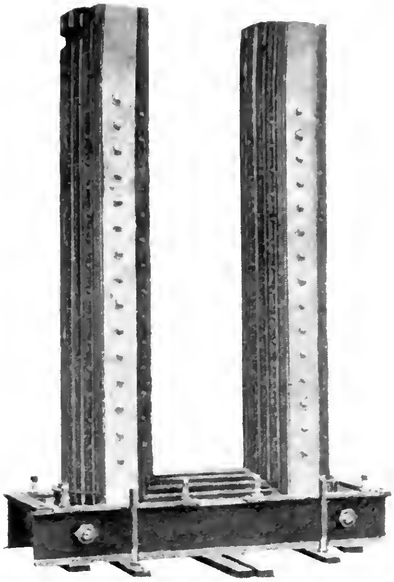

Fig. 9. Large Transformer Core Ready for Assembly

The necessary support to make the coils rigid and free from vibration, even under great overloads, usually can be best obtained by mounting the supporting insulation directly on the core. An independent structure might of course be used for the purpose, but so doing means extra material and neglect of the great inherent strength of a rigidly assembled core.

This condition is fully met, for example, by the two-legged core as shown in Fig. 9, which is built of straight punchings assembled with alternate lap and butt joints, bolted together and provided with heavy steel reinforcing plates. The joints between core leg and yoke are interleaved and secured by structural steel parts. The laminations in both the core legs and yokes have a square notch, so that when assembled a heavy insulated bolt of square cross-section fits into it at each corner. Thus the core is practically a one piece unit and together with the clamping structure forms a perfect support for the windings and major insulation which, when circular, can be tightly assembled and effectively ventilated by means of radially arranged spacing strips. The supports at the ends of the coils engage directly with the steel clamping structure, hence there can be no shifting of parts along the core axis, even under the most severe short circuit.

Naturally in the very large transformers the size of the core increases appreciably and if great care were not taken, excessive temperatures of core would result. Data are at hand so that both the internal and the surface temperature of all cores may be accurately predicted. In large units a number of ducts must be put through the center of the core, not only to keep the surface temperature within proper limits but to provide increased radiation near the center of the core and thus avoid too high an internal temperature.

In extremely large transformers, the cores in some instances consist of two complete concentric structures so that there exists an oil channel across the edges of the laminations in what is ordinarily the center of the core. Since the width of the punchings is thus decreased to less than half the overall dimension, the internal temperature rise is limited to practically as moderate a value as is used in the windings, although the insulations used on laminations and bolts can safely withstand very much higher temperatures indefinitely.

Second. Windings should consist of cylindrical or disc coils. For very high-voltage transformers they should be arranged concentrically, not interleaved.

An inherent mechanical weakness tends to exist in coils for large transformers because of their size, and, in very high-voltage windings, because of the large percentage of space that must be occupied by the insulation and the relatively small size of the conductor. It is, therefore, especially desirable that such coils be of the shape that is inherently the strongest to resist the strains they are called upon to withstand. Cylindrical, or helical, and disc coils wound with rectangular conductors comply with these conditions as the full tensile and beam strength of the conductor are available to resist these forces. Fig. 10 shows a typical low-voltage helical coil.

In general, it is the best practice because of its simplicity to use the interleaved assembly of high- and low-voltage coil groups up to moderate voltages such as 40,000, where it is desirable to keep the reactance as low as is consistent with the mechanical strength of the structure, and where an unreasonable amount of space is not lost by the repetition of the major insulation between groups. For higher voltage transformers the concentric assembly is desirable because of the resulting simplification of major insulation.

In a transformer the primary and secondary currents are always opposed to each other, and therefore, there is always a repulsion between primary and secondary windings. However, the different parts of the primary will attract each other and the coil group will be compressed. A similar action exists in the secondary. In the interleaved assembly, these forces all act in an axial direction and balance each other except at the ends of the coil stack. Here they are transmitted to the coil supports, which are an integral part of the core clamping structure, by means of spacers which are arranged radially at right angles to the conductors and support each turn at frequent and regular intervals. In the concentric assembly, the repulsion forces are radial, and as the coils are circular in shape, there is no tendency for distortion in this direction. Compressive forces are easily taken care of by the radial spacers between coils. If the high- and low-voltage windings are not symmetrical with respect to their horizontal center line, as when taps are not properly balanced, or when the coils are assembled with slight inaccuracy, a large force results which tends to move the coils along their vertical axis. Substantial coil supports must therefore be provided even with the concentric assembly.

The circular coil assembly has excellent thermal characteristics, as the narrow coil spacers at right angles to the conductors reduce to a fraction of an inch the length of the heat-conducting path from the center of the spacer to the oil, and thus the blanketing effect of the spacer is negligibly small.

Third. Major insulations should furnish rigid support to the windings and have ample strength to withstand stresses accompanying short circuits.

The major insulation is that placed between the high-voltage and low-voltage windings and between the high-voltage winding and grounded core. In the interleaved type, coils are stacked around one or more insulating cylinders surrounding the core leg. The "U" shaped spacers placed about each coil accurately and rigidly space them from the cylinder. Between the high- and low-voltage groups insulating collars are assembled as a part of the stack with oil ducts between them and the coils.

The concentric assembly of windings allows a very important simplification of the major insulation, by using a number of concentric cylinders between the core and low-voltage winding and between the low-voltage and high-voltage windings.

These insulating cylinders are highly laminated and are built up on steel forms under high pressure and temperature. Mechanically, they are practically as strong as the coils themselves and will resist temperatures much in excess of the highest oil temperature which it is safe to employ in transformers. They are so installed with longitudinal bracing as to give a continuous line of support from the outer circumference of the winding to the core. This precludes any movements of parts and closing of oil ducts and yet subdivides the total insulating space into many independent units, so that any foreign material would be unlikely to bridge more than one oil space in any radial direction.

The uniformity and rigidity of these arrangements enables much greater weight to be placed on other important factors of design than is possible in other types, such as the rectangular coil shell type, where they must be subordinated to a complicated and bulky system of rectangular collars, group casings, channel pieces, etc. The complete system is being repeated between each group of high-voltage and low-voltage members and consisting, in total, of hundreds of separate pieces for a transformer of extra-high-voltage.

Fourth. Taps should be avoided, but if used they should be located as far removed from the line connections as possible.

Mechanical considerations become more important with increasing kv-a. size and moderate voltages due to the higher ampere-turns located in a given space. With increasing voltage the spacing must be greater and, therefore, the densities of magnetic leakage flux less and the forces less. On the other hand, the increase in physical size (coil areas), due to increase in voltage, means that the total forces are greater for a given flux density. Therefore, it is quite important to be sure that the coil stacks are not unbalanced by the effect of "buffer" or end turns or by taps or various voltage connections. The forces may be in two directions; (a) radial and (b) axial.

(a) In the concentric type the principal mechanical forces are radial and tend to expand the high-voltage and to compress the low-voltage windings.

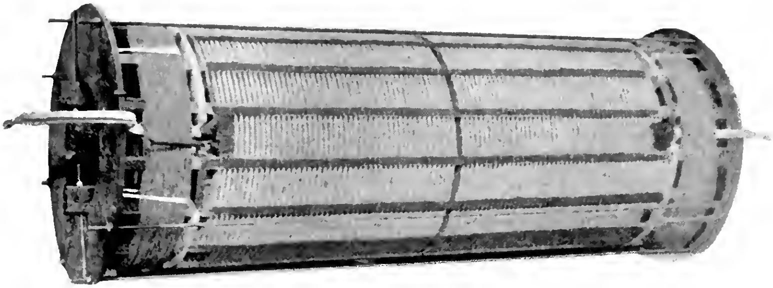

Fig. 10. Typical Low-voltage Helical Coil for Large Power Transformer. Coil is clamped preparatory to vacuum varnish treatment

In the interleaved type, with all coils properly centered, radial forces are encountered only when portions of a coil section are tapped out. For this reason an endeavor is always made on large units to avoid taps in individual coils. Special tap coils with the requisite number of turns are usually made so that the tapped portions of the winding are complete coils rather than parts of coils and the tap leads are taken from the crossovers between coils. This incidentally makes the problem of insulating the taps easier.

(b) To prevent as far as possible axial unbalancing in the concentric type, the taps are taken from the center of the coil stacks and so balanced that alternate taps are taken out on either side of the center, or in the case of very large transformers the taps are arranged to take equal portions on both sides of the center simultaneously.

Theoretically if the magnetic centers of high- and low-voltage windings coincide no axial forces exist tending to slide the windings with respect to one another. Practically this condition cannot be obtained even when the taps are carefully balanced. Unavoidable variations in manufacture make it necessary that ample allowance be given in calculating the forces for any reasonable lack of accuracy in coil assembly.

Fifth. The tank construction should be such as to exclude air.

The exclusion of air from the tanks of high voltage transformers is particularly desirable for several reasons.

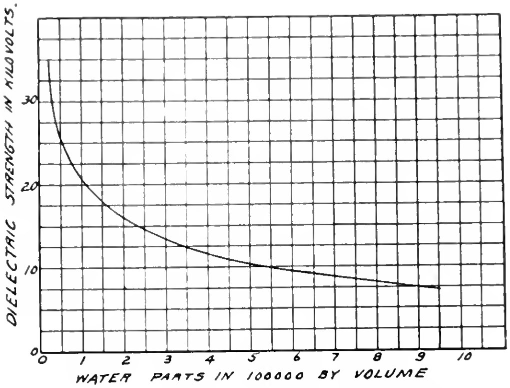

Fig. 11. Effect of Moisture on Dielectric Strength of Oil

(a) *Moisture*—Entrapped moisture is perhaps the greatest deleterious agent affecting high-grade insulation. The presence of an exceedingly small amount of moisture will reduce the dielectric strength of solid insulation to a mere fraction of its original value, by so changing the distribution of the dielectric stress as to cause a failure in what would ordinarily be a dielectrically strong structure.

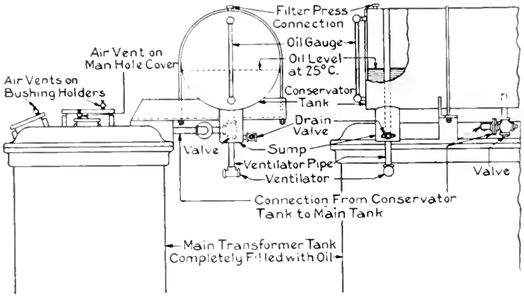

Fig. 12. Diagram Illustrating the Main Features of the Oil Conservator

The sensitiveness of oil to water has long been known; the effect on the dielectric strength being shown clearly in Fig. 11. Satisfactory transformer oil when received by a customer should stand a test of at least 22 kilovolts between one-inch discs spaced $^1/_{10}$-in. apart, and is unsatisfactory for high-voltage or large transformers when the dielectric strength is less than 75 per cent of this value; that is, when it is below 16½ kilovolts. By reference to the curve, it will be noted that oil of the standard strength, that is, 22 kilovolts, should have not more than eight parts of water in one million parts of oil, and that the addition of 10½ parts of water giving a total of 18½ parts per million will reduce the dielectric strength to the lowest permissible limit. With increasing capacity and higher voltage, the necessity of almost absolute protection of oil against moisture will be appreciated.

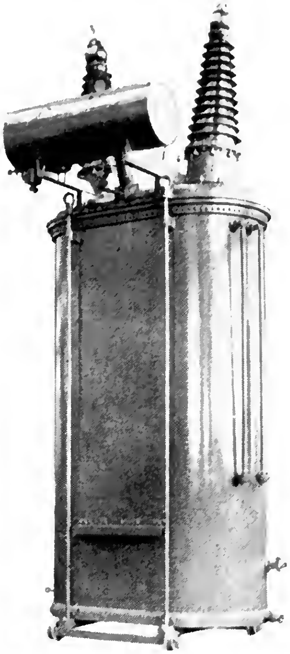

Fig. 13. Large Water-cooled Transformer with Conservator Tank

Evidently the most completely effective method of protecting against moisture is to have the tank cover and terminals air tight.

(b) *Explosion*—Due to chemical action in the transformer oil, caused by arcing or static discharges or heavy overloads, combustible gases (mostly hydrogen and light hydrocarbons) are sometimes set free, and in the ordinary tank these gases mix with the air above the oil so that a highly explosive mixture may be formed. This gas may be ignited by sparks of a static or dynamic character occurring along the leads, causing a dangerous explosion. While all General Electric high-voltage bushings are provided with grounded shields that make this impossible under ordinary circumstances, an abnormally low oil level may expose the lower bushing terminals, thus neutralizing the protection of the shields.

(c) *Sludging*—Hot oil, even if carefully selected, will very slowly decompose when in contact with oxygen, and a precipitate will be thrown down. This decomposition or sludging, while it does not affect the dielectric strength of the oil, increases the viscosity and thus retards the transfer of heat from the core and coils to the cooling surfaces. Even more deleterious is the fact that the deposit settles on the coil surfaces, in the ducts, and on the cooling coils. This acts as a heat insulator on all surfaces and also will in time clog up the ducts. The result is that the operating temperature gradually increases with consequent acceleration of the sludging.

The oil regularly supplied with General Electric transformers is of such a quality as to practically exclude sludging under normal conditions, yet continued heavy service with occasional overloads may eventually produce sludge.

An exhaustive series of tests has demonstrated that when air is not present the oil can be operated continuously with practically no sludging at a temperature that would prove disastrous if air were present.

(d) *Organic Acids*—Organic acids are found at the same time as sludge. These acids attack the fibrous insulating materials and tend to materially shorten their life. It has been proven by tests that in a transformer from which the air is excluded and the formation of acids prevented, the life of the insulation will be approximately the same as in a transformer not so protected which is operating at a temperature at least 10 deg. C. less.

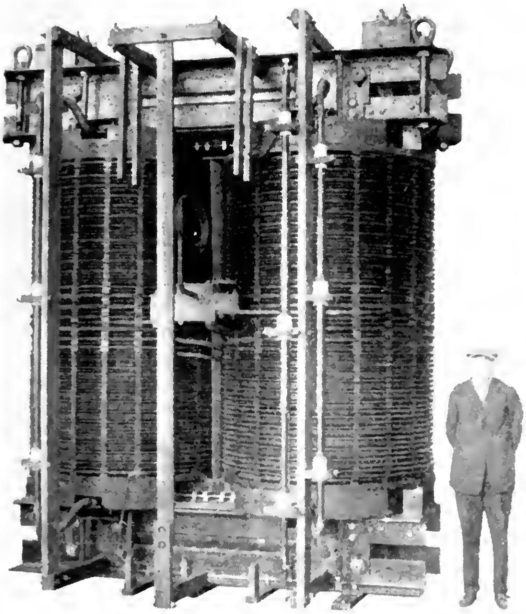

Fig. 14. Core and Coils of 20,000-kv-a., 220,000-volt Transformer

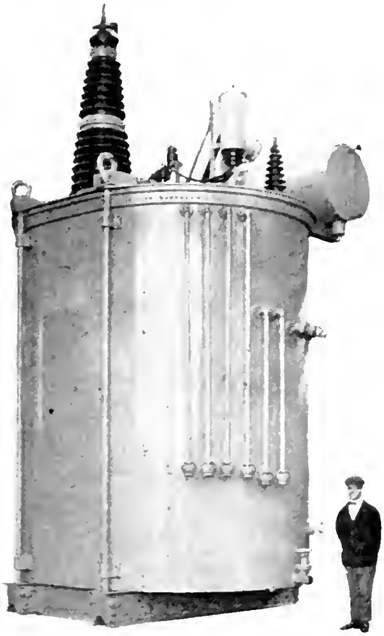

Fig. 15. 20,000-kv-a., 220,000-volt Transformer

The exclusion of air is effected by a simple addition to transformer tanks which is now extensively used by the General Electric Company. This device is called the Oil Conservator. Fig. 12 shows the arrangement and connections, and Fig. 13 shows the general appearance of this type of tank.

The conservator consists primarily of an auxiliary tank connected to the top of the main transformer tank by a suitable pipe and mounted somewhat above the level of the oil in the main transformer tank. When the auxiliary tank is supplied with oil the main tank and connecting pipe are completely filled, and the only oil that comes in contact with the air is that in the conservator.

Any moisture which may condense from the air in the conservator will collect in a sump, from which it may be occasionally drained. Any gas that may form in the main tank immediately escapes into the conservator where there is no possibility of ignition. There being only one oil connection of restricted size between the conservator and main tank, there is practically no circulation of oil and the temperature of the oil in the conservator is but slightly warmer than the outside air. Hence sludging of the oil with the accompanying formation of acids is prevented.

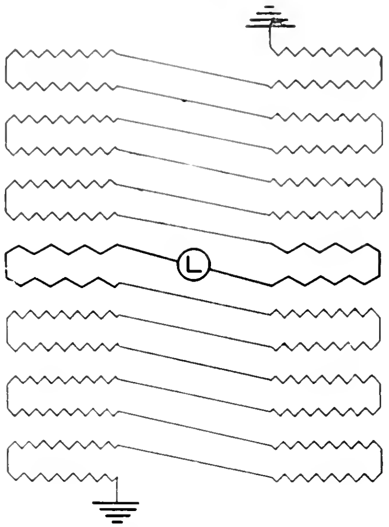

Fig. 16. Connection Diagram of High-voltage Side of 220,000-volt Single-phase Transformer for Y Connection on Grounded Neutral Circuit. Line enters at L; slanting lines indicate series connections between core legs. Diagram is schematic only; does not indicate number coils or their spacing

This construction has now been tested in service by the General Electric Company for the past seven years, there being installed about 1000 units with an aggregate capacity of 5,000,000 kv-a. The conservator is now furnished with all General Electric transformers designed for pressures of 80,000 volts and above, or for capacities of 2500 kv-a. and larger.

The foregoing features, standard in General Electric construction, are all embodied in the transformers described in the following and which also have several outstanding features.

Figs. 14 and 15 show a transformer of record-breaking size, seven of which have been recently built for the Southern California Edison Co. These transformers are water-cooled, single-phase, rated 20,000 kv-a. to transform from 220,000Y to 72,000 volts at 50 cycles. They are similar to previous designs for the same voltage, using a two-legged core with high- and low-voltage windings assembled concentrically. The high-voltage winding is designed for a permanently grounded neutral and is so disposed on the core legs that the coils adjacent to the yoke at the *ends* of the core legs are at substantially *ground* potential. Only one high-voltage bushing is required and the line lead is brought into the winding at the center of the coil stack, with two multiple circuits progressing in both directions to ground at the ends of the stack. This connection, shown diagrammatically in Fig. 16, which usually finds excellent application on extra-high-voltage transformers, effects a considerable saving, since it avoids the necessity of insulating the winding from its supports except for the voltage of one coil, and eliminates the striking distances and creepage surfaces which would be necessary at these points for ungrounded transformers.

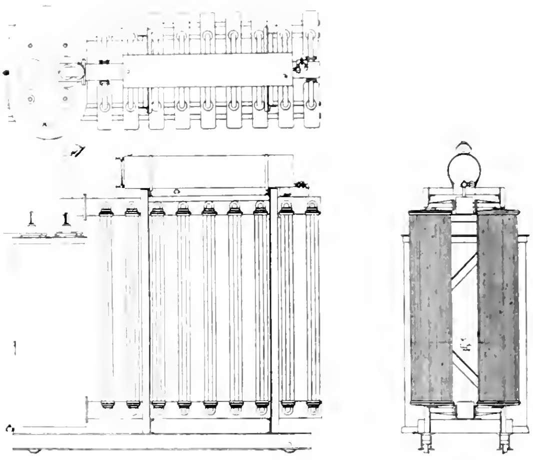

Fig. 17. Drawing Illustrating Arrangement of Radiators in Banks for Large Self-cooled Transformers

Since the transformers weigh nearly 160,000 lb. when filled with oil, a specially designed eight-wheel truck was necessary. The height over the cover is 16 ft., and over the high-voltage bushing 24 ft. The tank is of an elliptical shape, with axes of 10 and 12 ft.

A notable example of large single-phase self-cooled transformers is furnished by seven 60-cycle 10,417-kv-a. auto-transformers which will soon be put in service by the Brooklyn Edison Company. These transformers will step up the generator voltage from 13,800 volts to 27,600 volts. They have a transformer rating of 10,417 kv-a. but since they are auto-transformers of a one-to-two ratio, each will transform a total of 20,834 kv-a. so that the total output of a bank of three transformers will be 62,502 kv-a. This is probably the largest amount of energy transformed by a single bank of self-cooled transformers.

A novel feature of this design is the arrangement of radiators. The transformer proper is contained in an oval steel plate tank similar to the tanks used for water-cooled transformers. Attached to the top and bottom of this tank are two large rectangular manifolds on which are mounted the radiators in two parallel banks. The radiators and manifolds are supported on structural steel framework and the tank and the banks of radiators are mounted upon a long truck as shown in Fig. 17.

When installed, the transformer proper in its tank will be in a cell and there will be a door or baffle between the transformer tank and the banks of radiators, so that the complete unit may be rolled into the cell similar to a truck type switch, the transformer then being enclosed within its cell and the radiators projected outside and separate from the transformers. This construction, which was dictated largely by local space limitations, will undoubtedly find many applications on very large self-cooled units.

The transformer is provided with a conservator which is mounted above the manifold supporting the radiators and is connected with the outer end of the top manifold. The conservator is provided with the usual sump and breather.

The pressure relief diaphragm, to take care of any excessive pressures that may be generated in the transformer, is mounted on the elbow leading from the main tank to the top manifold so as to afford a free and unobstructed path for the oil to flow from the main tank to the pressure relief if it is called upon to function.

These transformers are also distinctive in the method of connecting the windings to the underground cables. Contrary to the usual practice of having standard outdoor porcelain bushings, they are designed so that the underground cables will be brought up with their lead covering directly into the transformer cover and connection so made that no live parts are exposed. There are no switches between the transformers and the cables, all the switching being done at the generator end of the cable.

The efficiency of these units is extremely high, being 99.4 per cent at full load, and 99.5 per cent at half load. These high values, which are of course always inherent in any auto-transformer, are further contributed to by the necessarily lower losses of a self-cooled unit over an artificially cooled design.

An example of the high efficiencies obtainable in a large, well designed transformer, even though not self-cooled, and for a low frequency, is furnished by some single-phase, 25-cycle, 22,000-kv-a. water-cooled transformers now under construction for the Niagara Falls Power Company. These units have guaranteed efficiencies of over 99 per cent. It is also of interest to note that these transformers, although designed for the moderate voltage of 68,500Y, will be the largest single-phase 25-cycle units which have been built, with respect to kv-a. rating. In physical size, their tanks are about the same as for the 20,000-kv-a., 220,000-volt transformers previously mentioned.

Characteristics and Performance of Conversion Apparatus for Edison Systems

By T. F. Barton and C. M. Fulk

Lighting Engineering Department, General Electric Company

The operators of Edison systems will find in this article information which will be of great value to them concerning the characteristics and performance of converters and motor-generators, particularly with regard to: starting, synchronizing, low-voltage connections, direct-current voltage range, voltage characteristics, load limiting, three-wire operation, enclosing features, effect of alternating-current disturbances, and re-energizing an Edison system.—Editor.

The synchronous converter and the motor-generator set are the two principal types of conversion apparatus in use in America. The progress in design of each type has kept pace with the general development of electrical apparatus and the requirements of the service. The problems connected with the operation of conversion apparatus have increased greatly with the growth of the direct-current systems, the multiplicity of alternating-current power supply of common and dual frequency, parallel operation of conversion apparatus of the same type and frequency or of different types and frequency, and with the more exacting requirements of the service. The thought given to all phases of this problem by the engineers of the operating and manufacturing companies has resulted in the development of a number of operating schemes with apparatus of special characteristics.

A general description of the more important operating schemes and of machine characteristics, together with results of tests on machines operating under normal and abnormal conditions, is the content of this article.

STARTING, SYNCHRONIZING, AND LOW-VOLTAGE CONNECTIONS

Converters

Methods of Starting: Synchronous converters may be started from the direct-current end as direct-current motors, from a direct-connected starting alternating-current motor, from taps on the low-voltage winding in the transformer, or by switching on the high side of the transformer where the high-voltage windings are connected Y in starting and delta in running.

All of the methods, except the last as applied to synchronous converters, are well known and a brief description of the last one is given.

From an economical standpoint, switching on the high-voltage side of the transformer applies to units of approximately 1500 kw. and above at 250 volts. For smaller units where alternating-current starting is required, the low-voltage tap method is usual.

Y-Delta Starting: The advantage of the Y-delta method of starting over the usual tap method is the elimination of the expensive low-voltage oil switches, or the unwieldy lever switches that are required for low-voltage starting, and the simplification of the low-voltage connections between transformer and converter. Also, it takes full advantage of the 30-deg. phase relation between the Y and delta connections.

The time required for the opening of the Y switch and the closing of the delta switch is approximately 0.3 seconds as a minimum, and maybe longer. The time required for the average converter to change its phase position 30 deg. is 0.7 seconds. The time in switching, therefore, can vary between 0.3 and 0.7 seconds with very little effect on the inrush current in switching from the starting to the running position.

The Y-delta starting in its simplest form gives 58 per cent starting voltage, but this voltage can be modified either above or below by placing taps in the high-voltage winding or adding an extended winding. Both arrangements have been used, depending on the conditions to be met.

Polarity Insuring: During the period of alternating-current starting, a potential is induced in the shunt-field windings that results in high voltage if the field is open circuited. The field can be divided into a suitable number of circuits to limit to a safe value the voltage across each, or short circuited through a discharge resistance or short circuited on the converter armature. With any of these field connections the converter may lock into step with either polarity. To fix the polarity with certainty, the field should be excited in the proper direction. Twenty per cent of no-load excitation is usually sufficient, and this amount increases the required starting kilovolt-amperes very little. The separate excitation scheme is now in general use. A double-pole double-throw switch with three positions is required. The starting position connects the field to a source of separate excitation, also across a discharge resistance so that the starting position is unchanged if the separate excitation source fails; the reversing position corrects polarity in the absence of separate excitation; and the running position provides self or separate excitation.

Alternating-current Low-voltage Connections: The transformers are usually connected delta high voltage and diametric low voltage for six-phase converters. The neutral point of each diameter is connected together to supply the neutral of the Edison system. With any scheme of starting, using transformer primary switching, the three neutrals can be permanently connected together and through some suitable disconnecting device to the system neutral. With low-voltage tap starting the common connection of the neutral to each phase of the transformer must be opened during the starting period.

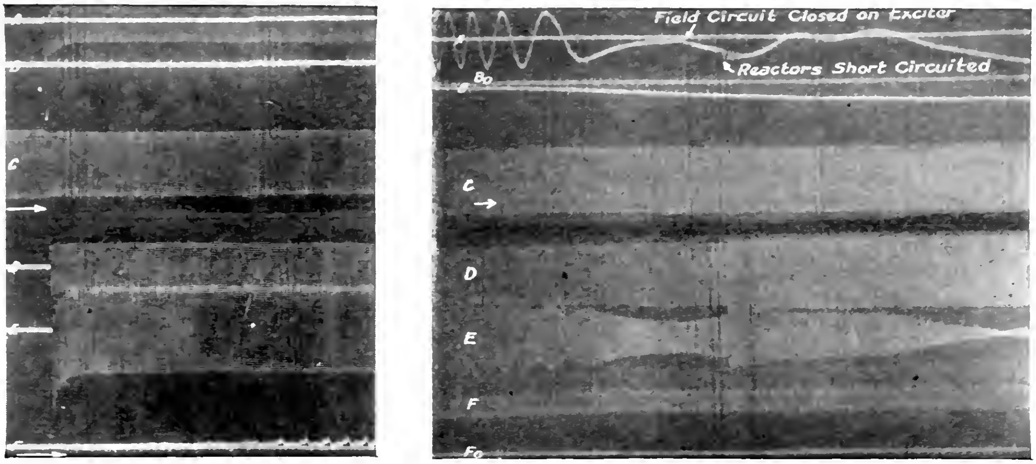

Fig. 1. Oscillograms of Starting Test of a 2500-kv-a., 60-cycle, 13,200-volt Synchronous Motor, Direct Connected to an 1875-kw. 250-volt Direct-current Generator. Field closed through resistor with 6.1 times resistance of field winding. Starting from line with 10 per cent series reactors

(Left) Initial start. (Right) Synchronizing, showing closing of field circuit on exciter and short circuiting of reactors. Curve *A*, Motor field current; *B*, D-C. generator terminal voltage; *C*, A-C. line voltage; *D*, A-C. motor voltage; *E*, A-C. line current (also motor current); and *F*, Speed of set

The loss and reactive drop of the low-voltage connections between transformer and converter are a function of the length of run and the arrangement of the leads. In many 60-cycle installations this loss amounts to more than one per cent in efficiency, and the reactive drop to 5 per cent of the converter voltage.

To reduce both loss and reactance to a minimum the low-voltage connections should be short. Sixty-cycle air-blast transformers can be made of such dimensions as not greatly to exceed the space between collector and base line, and between the magnet frame and the end of the shaft. For such a transformer location the collector ring stands are turned 90 deg. from the usual top or bottom connection. The collector rings are connected to the armature in proper phase relation with respect to the transformer terminals, to result in simple short connections with no cross-overs.

Motor-generator Sets

The following methods have been used for starting motor-generator sets: Direct-current starting, compensator starting, Y-delta with or without reactor and series reactor The first two methods are in general use for motor-generator sets in Edison service. Recently, principally because of automatic substation application, the Y-delta with or without reactor and the series reactor are used. The series reactor is the simplest possible form of starting but has the disadvantage of requiring high starting kilovolt-amperes since the motor current is drawn directly from the alternating-current lines. Its use will necessarily be limited to sets 5 per cent or less in terms of connected generating capacity.

Fig. 1 is an oscillograph record showing the starting period of an 1875-kw. motor-generator set using series reactor for limiting the starting current. The motor of this set is especially designed for reactor starting, and is furthermore designed to take full advantage of the voltage that is impressed on it as it approaches full speed to develop a high torque so that the generator may deliver approximately full output before the motor synchronizes.

The next simpler method of starting is the Y-delta without reactor. This method permits of limiting the starting kilovolt-amperes to approximately 135 per cent (as compared with 250 per cent for series reactor alone), and if the change from Y to delta is made at the proper time the inrush current will not exceed the 135 per cent kv-a. The reactor is sometimes used with the Y-delta starting method if it is desired to operate the machine on the delta connection after an interruption of power, and to resynchronize from low speed on the running connection.

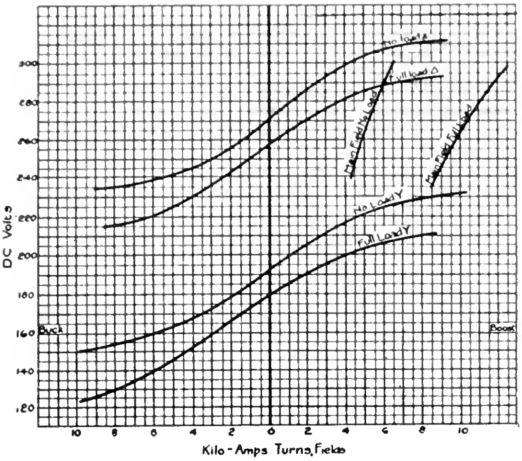

Fig. 2. No Load and Full Load Voltage Range of 13,000-amp., 225/285-volt, Direct-current, 60-cycle Synchronous Booster Converter with 80 Per Cent of Transformer High-tension Winding Connected in Y and Full High-tension Winding Connected in Delta

The connections and excitation of the field circuit have a marked effect on the kilovolt-amperes required at any speed in the starting period, also on the torque developed at any speed. The open circuited field winding gives the lowest starting kilovolt-amperes and the highest starting torque. The speed at which the maximum torque is developed depends on the design of the amortisseur winding, and with low-resistance windings the maximum torque is at approximately 90 per cent speed. By applying excitation to the field with the motor at approximately 95 per cent speed, the motor will pull into step a load that it will bring to 95 per cent of speed by its induction-motor-torque characteristic. Automatic devices are available to control the field circuit for the most efficient operation.

DIRECT-CURRENT VOLTAGE RANGE AND VOLTAGE CHARACTERISTICS

Synchronous Booster Converter

Booster Capacity: Synchronous converters with direct-connected or motor-driven boosters have usually been designed to give a voltage range on the direct-current end of plus and minus 11 per cent and in no case exceeding 15 per cent. For a voltage range exceeding this amount it has been usual to use the motor-generator set. Two principal features determine the capacity limit of the direct-connected synchronous booster. With the synchronous booster consuming a part of the line voltage and lowering the converter voltage, the converter operates as a generator in parallel with itself as a converter by an amount equal to the output of the booster as a synchronous motor. The compensating effect of the alternating current in the converter armature is decreased, which requires an increased excitation on the commutating pole in order to maintain commutation, but a point is reached where commutation cannot be successfully maintained. With the booster operating as a synchronous generator driven by the converter, commutation is effected in the opposite direction, requiring a decrease in excitation on the commutating pole, but the reactions are such that if the excitation is properly decreased commutation can be maintained. Another effect, however, comes into the operating characteristic of the machine in the boosting position which results in a tendency for the unit to pulsate if the booster capacity is more than a certain

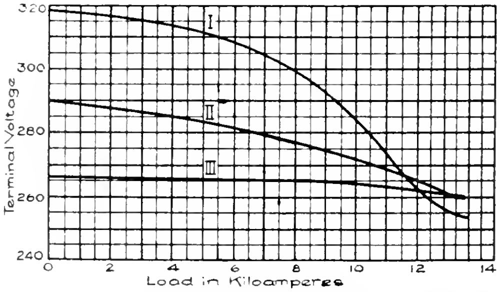

Fig. 3. Voltage Regulation of 13,000-amp., 225/285-volt, Direct-current, 60-cycle Synchronous Booster Converter

Curve I. With differential booster exciter

Curve II. Self-excited main and booster field rheostats unchanged

Curve III. Self-excited booster rheostat unchanged, power-factor held by main field percentage of the converter capacity. No trouble has been experienced when the converter operates at neutral or bucking.

A number of tests by an operating company showed that pulsation might result under certain conditions of boost. In all tests of single-unit operation there was no pulsation under any condition; with units in parallel, however, any condition starting pulsation would result in a gradual building up of the oscillations unless conditions were promptly changed or load entirely removed.

Compensated Booster: The voltage drop across the booster armature winding due to full-load current flowing and without excitation on the booster field is about 66 per cent of the rated booster voltage. A large component of this voltage is due to armature reaction. Compensation by a series winding such as used for compensating direct-current generators would greatly reduce the voltage generated by armature reaction, and in so doing would reduce the core loss of the booster, improve the phase relation between converter and booster resulting in greater booster range and lower main field strength to hold unity power-factor at the collector rings. The copper loss of the compensating windings would be offset by the reduction of booster core loss.

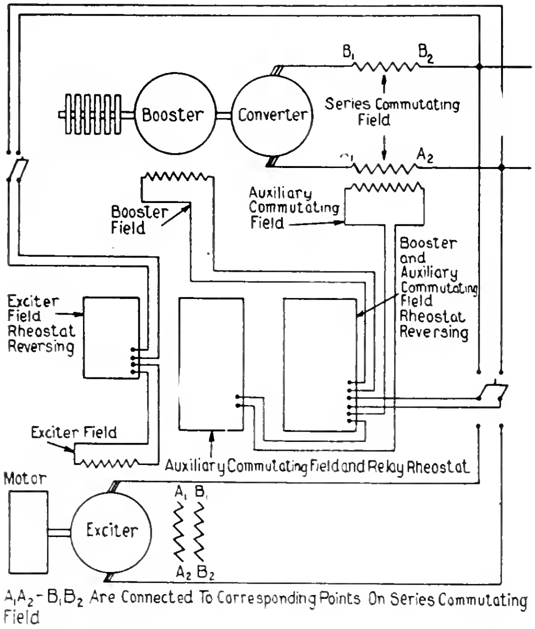

Fig. 4. Diagram of Connections for Synchronous Booster Converter Arranged to Excite Booster Field from the Converter or from a Differential Exciter

A booster with compensating windings has been built and tested in service. The form of the compensating windings was such that the bars of each pole connected together at each side of the pole to form an amortisseur winding. The single winding, therefore, served a double purpose.

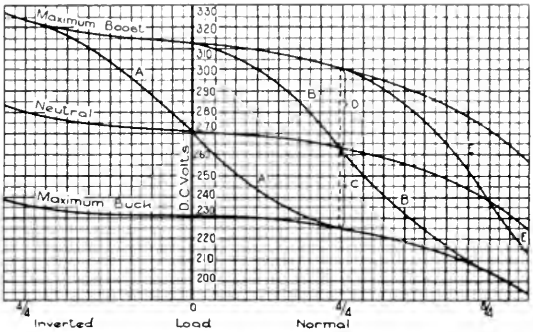

Fig. 5. Voltage Regulation of 240/300-volt Direct-current Synchronous Booster Converter

Curves at maximum boost, neutral, and maximum buck, all with booster excited from the converter

Curves *A*, *B*, and *E* all made with booster excited from differential exciter

The converter with this special booster has been fully tested and a great improvement in stability when boosting was found. Tests were made with and without excitation of the compensating winding and apparently the compensating feature did not noticeably affect stability. Compensation did give the other results expected. The connections of the converter are rather complicated by the

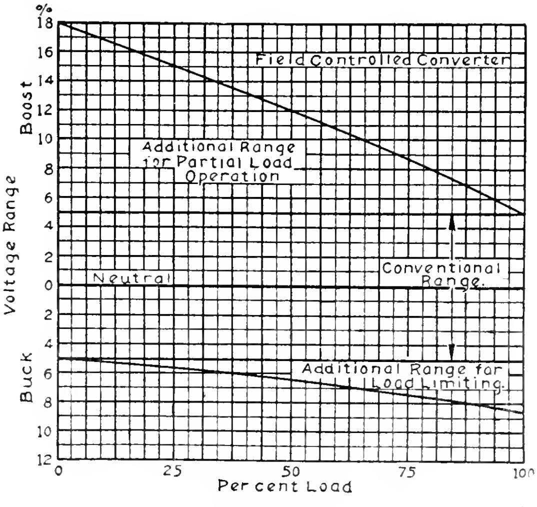

Fig. 6. Relation of Voltage Range to Load, 4200-kw., 25-cycle Field-controlled Converter

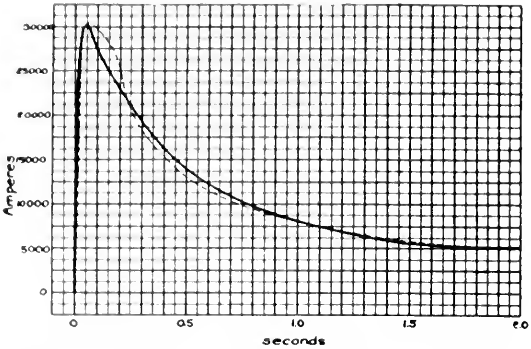

Fig. 7. Short-circuit Currents of 1200-kw., 250-volt, Direct-current Generator Driven by Synchronous Motor

Solid curve, with differential series field
Dotted curve, with current regulator

addition of compensation, especially if the unit is of the three-wire type. It is preferable, although not necessary, to split the compensating winding for three-wire operation.

For the present, at least, the additional complications in connections appear to more than offset the advantages of compensation. The amortisseur winding feature will, however, be used where a converter is to operate from reduced voltage taps and over the complete booster range on each tap.

Voltage Range and Regulation: The voltage range of a standard 13,000-amp. 60-cycle 225/285-volt synchronous booster converter at no load and full load and unity power-factor at 100 per cent alternating-current voltage, transformer delta connected, and 72 per cent voltage transformer Y connection, including 80 per cent of the winding, is shown in Fig. 2. Some additional voltage range is obtained by power-factor control.

The inherent voltage regulation of the synchronous booster converter depends on the regulation of the converter itself, which depends principally on the brush position and the strength of the commutating field, the regulation of the transformer and intermediate connections, and the regulation of the supply. On the basis of a constant supply voltage the regulation of the self-excited shunt-wound synchronous booster converter at unity power-factor is approximately 2.5 per cent. The regulation with constant rheostat setting is approximately 11.0 per cent. The regulation curves for both conditions are shown in Fig. 3.

Differential Booster Exciter: The voltage of the synchronous booster can be varied at will and it can be varied automatically with load in order to increase the inherent regulation of the synchronous booster equipment. This might be accomplished by placing a series differential winding directly on the poles of the booster, but in practice it has been found more economical to use a separate exciter for the booster field winding, and the fields of the exciter arranged with a differential winding. The exciter is designed with sufficient series differential field to give full voltage change of the booster field excitation for 100 per cent change in converter output, that is, with the converter operating at no-load neutral voltage

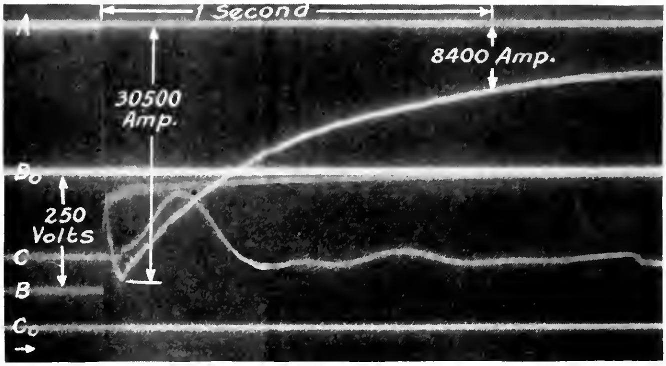

Fig. 8a. Load Limiting by Differential Series Field, Multipolar 1200-kw., 720-r.p.m., 250-volt, Direct-current Generator with Pole-face Winding

Curve *A*, Direct current; Curve *B*, Direct-current voltage
Curve *C*, Synchronous motor field current

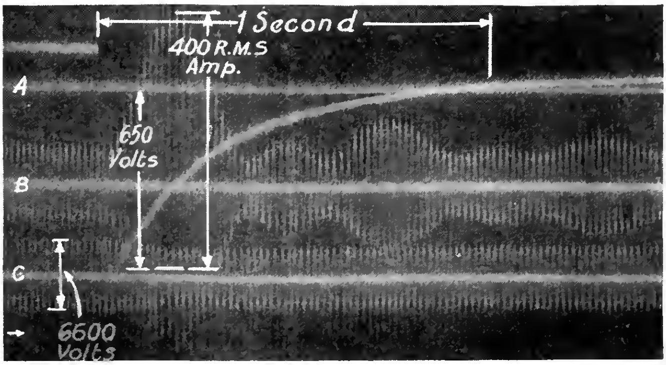

Fig. 8b

Curve *A*, Induced voltage generator field; Curve *B*, Alternating-current motor
Curve *C*, Alternating-current voltage, motor

the exciter would be operating at zero voltage; adding 100 per cent load to the converter would add 100 per cent excitation to the exciter in the direction to give full excitation for the booster and in the direction to buck the converter voltage.

The differential exciter does not increase the voltage range of the synchronous booster converter as the available voltage range is determined entirely by the capacity of the booster. It does change the voltage regulation, however, adding to the inherent regulation one-half of the booster range, provided the maximum buck or boost limit is not reached by the load change. The third curve of Fig. 3 shows the voltage regulation of the synchronous booster converter with the differential exciter.

The connections of the differential exciter as a spare to the usual booster and auxiliary commutating field rheostat is shown in Fig. 4. The regulation of the booster converter with differential exciter is given in Fig. 5, as curves AA, BB, and EE which show clearly the limitations, depending on the point of initial operation.

Field Control Converter

The field control converter has a limited voltage range with plus and minus 5 per cent as about the economical limit. The inherent regulation of the field control converter is much greater than the synchronous booster converter because of the greater amount of reactance in the circuit. The voltage range curves are shown in Fig. 6. The field control type is well suited for automatic substation work, also on some of the larger systems where the required voltage range is small.

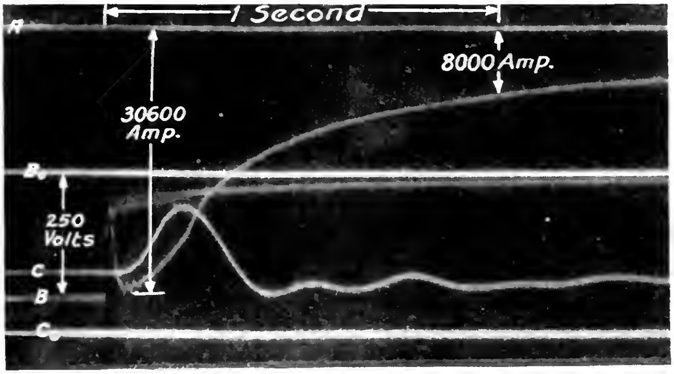

Fig. 9a. Load Limiting by Counter-Electromotive-Force Regulator, Multipolar 1200-kw., 720-r.p.m., 250-volt, Direct-current Generator with Pole-face Winding

Curve *A*, Direct current; Curve *B*, Direct-current voltage
Curve *C*, Synchronous motor field current

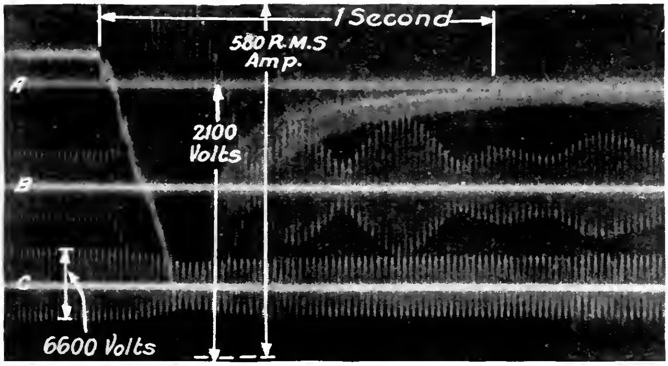

Fig. 9b

Curve *A*, Induced voltage generator field; Curve *B*, Alternating-current motor
Curve *C*, Alternating-current voltage, motor

Motor-generator Sets

A voltage range of 100 per cent is available from the generator provided a suitable scheme of excitation is used. The shunt-wound separately-excited machine allows 100 per cent voltage range; the self-excited machine allows approximately 25 per cent voltage range unless special construction is used, increasing the voltage range to approximately 50 per cent. The self and separate excitation of the shunt winding, together with differential series excitation provides 100 per cent voltage range, also the constant current characteristic which is not obtained by any other form of excitation. Successful commutation over the complete range of voltage is obtained on the generator of the compensated commutating-pole type.

LOAD LIMITING

Synchronous Converters

Load limiting is obtained by decreasing the voltage impressed on the load; and in the case of the synchronous converter the range over which the voltage can be controlled is somewhat limited.

As previously pointed out, it is not desirable to use a direct-connected booster of more than 15 per cent capacity. The converter can be operated over a much greater range in voltage if it is operated as a simple converter, which is obtained by tap changing on the transformer, a separate motor-driven booster set, or some form of induction regulator. The standard 250-volt converter will operate successfully at approximately 75 volts. Below this voltage it is necessary to make further reduction by inserting in the line leads a resistance which is divided into a suitable number of steps to be cut in and out of circuit by short circuiting devices.

Air cooled resistors are usually used for short time ratings but for time settings exceeding 15 min. the water-cooled resistor becomes the more economical proposition, both from the standpoint of cost and space required.

Motor-generator Sets

Series resistance has been used in some cases for load limiting in the case of motor-generator sets, but for lighting and power work field control gives very satisfactory results.

There are two methods of field control of the generator for load limiting purposes. One is by regulation of the shunt field only, and the other by a differential series winding, the strength of which is varied by a shunting device in combination with a shunt-field excitation of which approximately one-third is furnished by separate excitation and the remainder by self excitation. The shunt winding may consist of two separate windings, one of which connects to the constant source of excitation and the other to the generator terminals, or it may consist of a single winding. In this case a 125-volt exciter is connected in series with the 250-volt generator and the shunt-field winding connects across the two in series.

The two methods of control have been carefully tested and there appears certain advantages for the second in that the inherent voltage-current characteristic can be made such that the machine becomes practically a constant-current generator at full-load current. Fig. 7 shows the results of the two methods of field control for load limiting purposes taken on a 1200-kw. 250-volt motor-generator set. Shunt-field control was obtained by the use of a counter-electromotive-force regulator with the aid of a contactor shunting a suitable amount of resistance for quickly lowering the voltage to a point where the regulator would take hold and maintain constant current. The time element of this short circuiting contactor was eliminated by energizing the contactor to trip immediately before making the short circuit. While this is not a practical arrangement for service conditions, it was made a part of this test so as to show the best results that can be obtained from this method of load limiting.

The curves shown in Fig. 7 are taken from the oscillograph records shown in Figs. 8 and 9. Fig. 8 is the record of load limiting by differential field control. Fig. 9 is the record with a constant-currrent regulator control. The resistance, amounting to 0.0007 ohms, through which the generator was short circuited, was exactly the same in both tests. It is clearly seen by comparing the two oscillograph records that load limiting is effectively obtained by either scheme. The differential field winding is slightly faster as indicated by the direct-current curves, also by the motor-input current curves. The shunt-field voltage is very different in the two cases where 650 volts is the maximum reached with the differential field control as against at least 2100 volts with the constant-current regulator control.

A great advantage of the differential field method of control is the absence of all regulating devices, also the current limiting effect of the differential winding that becomes cumulative should the direction of power change. The compensated commutating pole generator may be unstable when operating as a motor at low voltage and at high current. This instability is entirely overcome by the action of the compound winding.

THREE-WIRE OPERATION

The synchronous converter is easily arranged for three-wire operation, also practically any amount of unbalance can be successfully handled. Observations of machines operating under conditions of 100 per cent unbalance, that is, rated current in one lead and the neutral lead and zero current in the other main lead, show no perceptible difference in the operation of the machine as compared to balanced conditions. In order to successfully commutate such conditions the series commutating field windings must be arranged to include one-half the winding in each side of the line, also the commutation control for the auxiliary commutating field must be so arranged that the excitation of the auxiliary commutating field depends on the output as measured in each of the outside leads.

If the unbalance is 10 per cent or less it is not necessary to split the series commutating field windings, and a number of units for three-wire operation have been so arranged in order to preserve the simplest possible field connections.

In the case of the motor-generator set it may be difficult to provide for three-wire operation, principally because of the complicated field connections that result, and because of the small amount of clearance between field connection strips of opposite polarity. This is particularly true where a compound or a differential-compound machine is used so that there are three windings that must be split and connected in each of the main leads, that is, the series winding, the commutating field winding, and the compensating field winding.

The amount of unbalancing of a system as a whole and at any individual substation is usually small in percentage, and an effort is made by the distribution department to maintain approximately balanced conditions throughout the distribution. Changes are necessary from time to time to accomplish this result.

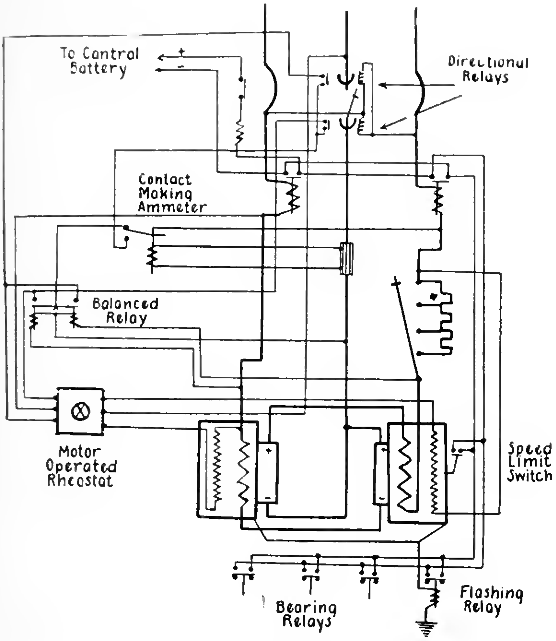

Fig. 10. Diagram of Connections for Direct-current Balancer Set and Control Auxiliaries

It should be fully appreciated that in three-wire operation the amount of unbalance on the converter or the generator results in the lowering of the total output from the machine. The heating and performance of a machine are based on rated current. If the rated current is not exceeded in the heavier loaded side then the output of the machine is decreased in per cent by half the per cent of the unbalance. At 25 per cent, an amount usually considered as a maximum for continuous operating conditions, 12½ per cent of the machine capacity is forfeited.

In a system supplied by converters and motor-generator sets it is usually possible to obtain the necessary neutral capacity from the converter, operating all of the motor-generator sets as two-wire units. In certain cases, however, this has not been possible because of the relative location of the motor-generator sets and converters.

Balancer Set: A balancer set with special field connections and control has been developed. Each unit of the set is provided with a series winding that has a differential relation when the unit is a generator, and an accumulative relation when the unit is a motor. The poor voltage regulation due to this field connection is compensated for by the automatic control of the shunt fields of each machine to maintain a balanced voltage condition until the capacity of the balancer set is reached, at which point no further change is made in the shunt-field adjustment for voltage balance. Beyond this point the shunt field is automatically adjusted to limit the neutral current which protects the set within certain reasonable limits. A balancer set of this type can be permanently connected to the system and will follow any voltage changes. Fig. 10 shows the simplified wiring diagram and control.

ENCLOSING FEATURES

Enclosing features for both converters and motor-generator sets are being given more and more consideration because of the special problems in ventilation and in quietness of operation. It is a fairly simple matter to enclose the motor, and this has been standard for a number of years. It is much more difficult to supply suitable enclosures for the commutating machine because it is desirable to have the commutator and brushes visible and accessible. Generators have been enclosed so as to take air from an intake air duct and discharge air at the commutator end, but without any enclosure of the commutator or any means for discharging the air directly into a discharge duct. Synchronous converters are now being built to take air from the room and discharge to a suitable discharge duct, also to take air from an intake duct and discharge to the room. In both cases the arrangement of enclosure is such as to produce quietness of operation. Developments along this line have just started and it is believed that considerable progress will be made during the next few years. Quietness of operation and ventilation are two of the big problems in any downtown substation.

EFFECT OF ALTERNATING-CURRENT DISTURBANCES

Converters

Power Transfer: The lowering or raising of the alternating-current voltage to the converter causes a corresponding change in the direct-current voltage and, therefore, during alternating-current disturbances where the alternating-current voltage may drop to very low values for periods of time the direct-current voltage tends to drop, and if it is maintained from another source of supply a current will flow from that supply into the alternating-current system, depending upon the difference in voltage of the supply and the alternating-current system. In most systems it is very desirable to have continuous operation of the synchronous converters and it is, therefore, desirable to meet the conditions produced by alternating-current disturbances without permanently disconnecting the converter from either the alternating-current or the direct-current system. This problem has been carefully investigated and a series of tests were made to determine the effect of alternating-current disturbances on 60-cycle synchronous converter operation and what forms of protection are necessary in order to have the machine successfully meet these conditions and continue in operation at the termination of the alternating-current disturbance.

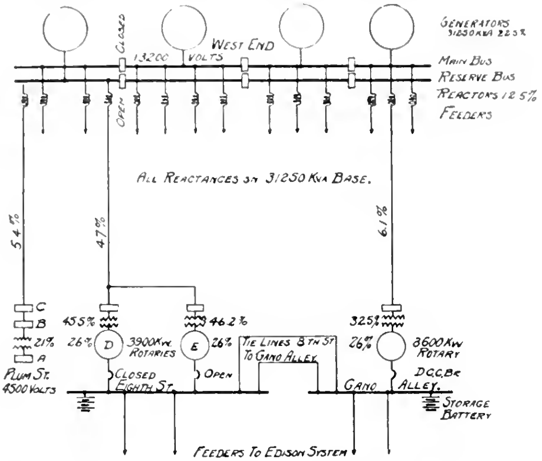

Fig. 11. System Connections During Alternating-current Short-circuit Tests, 3900-kw., 240/300-volt Synchronous Booster Converter with 3-phase 13,200-volt Transformer. Short Circuits made at *A* (4500 V.) and *B* (13,200 V.)

A, Short-circuit closing O.C.B., 4500 volts; *B*, Short-circuit opening O.C.B.; *C*, Aux. short-circuit opening O.C.B., 13,200 volts; *D*, Converter withstanding short circuit; *E*, Converter floating on line

The inherent voltage regulation of the converter is small and therefore a small change in the relation of alternating-current and direct-current voltage causes the converter to drop its load and invert. The inherent regulation of the booster converter can be increased by bringing into action the voltage range of the booster, and the two in combination permit a much greater change in the relative relation of alternating-current and direct-current voltages for the same change in load. The effect of both, however, is not sufficient to limit to safe values the amount of reverse current which results from a severe disturb-

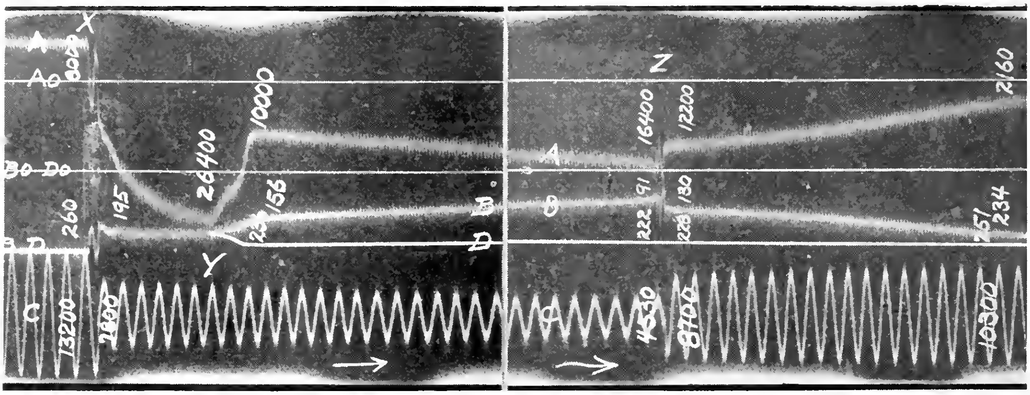

Fig. 12. Three-phase 13,200-volt Short Circuit at *B*, Fig. 11

Curve *A*, Direct current; Curve *B*, Direct-current voltage, converter; Curve *C*, Alternating-current voltage to transformer
Curve *D*, Direct-current voltage substation bus; Curve *X*, Short circuit on; Curve *Y*, Current limiting resistor in
Curve *Z*, Alternating-current short circuit opened

ance on the alternating-current system such as is due to a short circuit on the primary distribution and where the direct-current voltage is stabilized by storage battery capacity connected to the system or other conversion apparatus not affected by the alternating-current disturbance.

The system connections for the tests at Cincinnati are shown in Fig. 11. It was found that a short circuit on the secondary distribution (4500 volts) would produce an alternating-current disturbance of sufficient magnitude when one generator (31,250 kv-a.) was in operation to cause approximately 200 per cent reverse current to flow from the direct-current system supplied by batteries to the alternating-current system. This disturbance would be less with more alternating-current generator capacity connected, but each test was taken to cover the worst case. This test clearly indicated that it would not be possible to operate the converter permanently connected to the alternating-current and direct-current systems when the alternating-current disturbances were of the order produced by a short circuit on the primary distribution. To obtain additional regulation on the converter circuit an air-cooled resistor, short circuited by a breaker, was connected in the line lead. The action of reverse current opens this circuit breaker shunting the resistor and the resistor remains in circuit until the effect of the disturbance is past, allowing voltage restoration and current flow in the normal direction which closes the breaker across the resistor and the machine is again directly connected to the system delivering load. Fig. 12 is an oscillograph record of these conditions. Fig. 13 is an oscillograph record of a short circuit on a 4500-volt feeder.

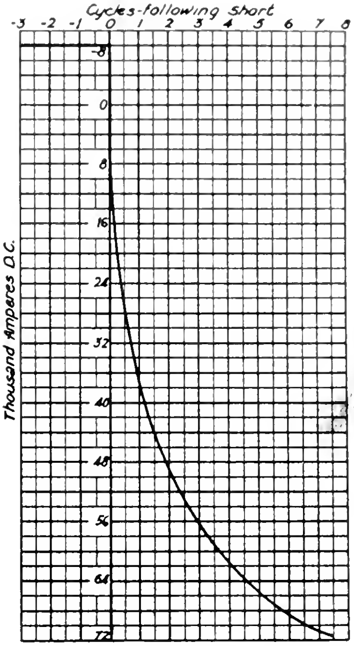

Fig. 14. Estimated Direct Current for 3-phase Short Circuit on Feeder Supplying 3900-kw. Converter, Fig. 11

The performance of the 60-cycle converter is very creditable under the conditions shown in Fig. 12, although there is an instantaneous change in load of almost 250 per cent.

Tests indicate that the synchronous converter carrying load in either direction will operate successfully at about 25 per cent

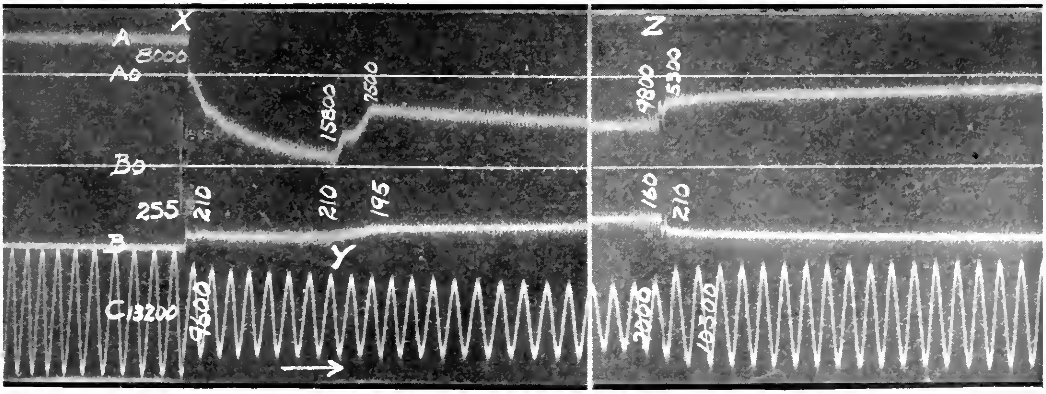

Fig. 13. Three-phase 4500-volt Short Circuit at *A*, Fig. 11

Curve *A*, Direct current; Curve *B*, Direct-current voltage, converter; Curve *C*, Alternating-current voltage to transformer Curve *X*, Short circuit on; Curve *Y*, Current limiting resistor in; Curve *Z*, Alternating-current short circuit opened voltage and at no load at a lower voltage. The Cincinnati tests show the results when a short circuit occurs on a radial feeder that is not supplying the synchronous converter equipment under test. If the feeder supplying that converter were short circuited then it would be necessary to disconnect the unit on the direct-current end and there is no advantage in it remaining connected to the alternating-current end. Fig. 14 shows the estimated current flow had the alternating-current feeder supplying the converter been short circuited.

In the preceding paragraphs the supply to the direct-current end of the converter was obtained almost entirely from the storage battery that connects to the substation bus. If no storage battery is connected to the bus then the direct-current supply must come from the system and, therefore, over the resistance drop of the connecting feeders, or must come from other machines in the same station that are fed from a separate source of alternating-current power that is not involved in the disturbance, or from the generator of a motor-generator set (the voltage of which is not directly affected by the alternating-current disturbance even though the motor-generator is operating from a common source of supply with the converter).

Commutation: To compare the performance of a converter carrying load as against a converter running light when subjected to the same alternating-current disturbance, two similar machines were observed during these tests, one machine loaded and the other running light. The sparking at the commutators of the two machines was practically the same; in other words, the presence of high direct-current load currents made very little difference in the performance of the unit.

The series commutating field strength will follow the load changes but the auxiliary commutating field strength has a considerable time lag due to the time required to move the rheostats. Reducing the time lag to a minimum would change the net results very little because of the inductive relations between the shunt and series windings on the commutating pole. This inductive effect is shown by the curve of auxiliary field current in Fig. 15. If conditions allowed the apparently correct field currents, the field adjustment would not be correct because of the unbalanced relation of alternating-current and direct-current component currents in the armature conductors. As an indication of the order of these effects Fig. 16 shows the line current and the commutating field current resulting in connecting and disconnecting load from a converter. Fig. 17 shows the line and field current where the commutating winding is short circuited before the line breaker is opened. The observed flashing at the commutator in the second case was about the same as the first, although a greater load is switched on and off.

If the direct-current bus in the case of these tests had been supplied by a converter of equal size and from a source of supply that was not affected, the amount of reverse current would have probably been of the same general order as that obtained from the battery in this particular case. In other words, the voltage regulation of the 13,000-amp. converter is

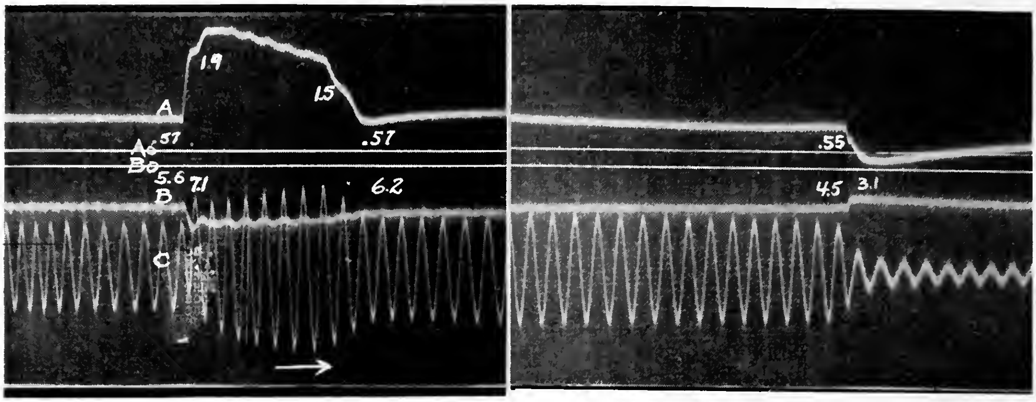

Fig. 15. Currents in Booster and Auxiliary Commutating Fields at Time of Tests, Fig. 13

Curve *A*, Current, auxiliary commutating field; Curve *B*, Current, booster field; Curve *C*, Current to transformer
Curve *X*, Short circuit on; Curve *Y*, Current limiting resistor in; Curve *Z*, Alternating-current short circuit opened

about the same as shown on the voltage-current curve of Fig. 3.

Parallel Operation: From the foregoing it is clear that the same general problem exists where converters are operating in parallel with batteries, or in parallel with converters of the same frequency and independent power supply, or different frequency and power supply, or with motor-generator sets from the same or separate power supply.

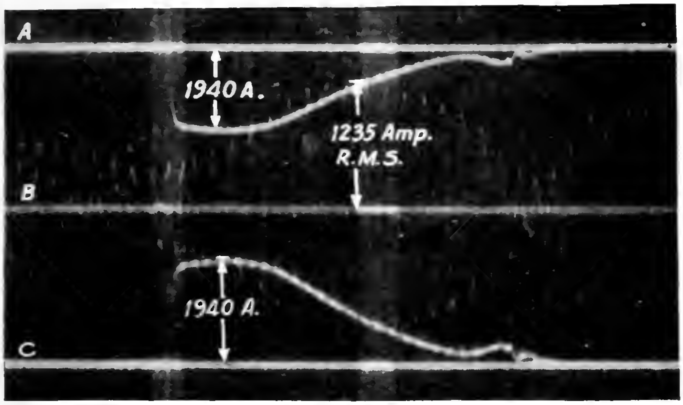

Fig. 16. Compound-wound 300-kw., 1200-r.p.m., 750-volt Converter Short Circuited Through 0.268 Ohms. Transformer Reactance 15.0 Per Cent

Curve *A*, Current, commutating field; Curve *B*, Alternating current
Curve *C*, Direct current

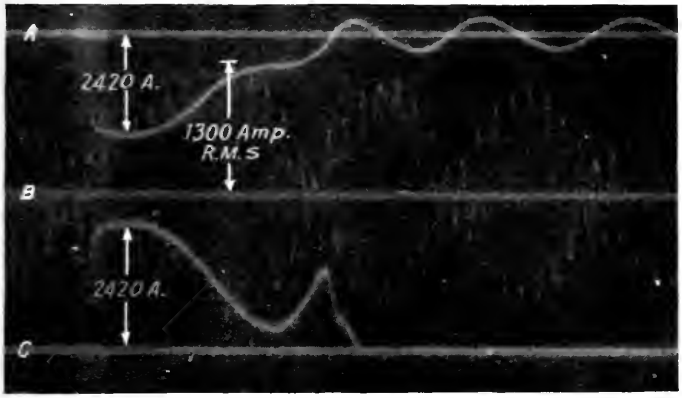

Fig. 17. Compound-wound 300-kw., 1200-r.p.m., 750-volt Converter Short Circuited Through 0.238 Ohms. Transformer Reactance 15.0 Per Cent. Commutating Field Short Circuited Before Opening Direct-current Breaker

Curve *A*, Current, commutating field; Curve *B*, Alternating current
Curve *C*, Direct current

Operating experience shows that alternating-current disturbances will cause heavy reverse current under any of these conditions. This fact has led operating companies to provide suitable ties between the several sources of power supply where synchronous converters are operating from each and are paralleled on the direct-current end. If the two supply systems are not tied together except through the converters, then the converters must of necessity handle the current flowing between the two systems, attempting to maintain the normal voltage relations.

Fig. 18 shows the connections of a number of converters in several substations supplied by two generating stations that are not connected together except through the converters on the direct-current end. The connections shown are those existing at the time of a known alternating-current disturbance and the effects on the several machines were noted. No direct-current reverse-current protection is used in this case and the machines are disconnected from the alternating-current end by the operation of inverse time overload relays, and from the direct-current end by the operation of the overspeed switch. It is significant that the only machine showing distress is at the West 41st Street substation, and this machine is fed by another unit of equal capacity and by a small amount of battery capacity. Fig. 19 shows the connections and capacities involved for another form of alternating-current disturbance, and here again the machine showing the effects of the disturbance was supplied by units of greater capacity connected to the same bus. At West 26th Street the brushes of the 4200-kw. unit were badly burned. This unit was connected to a direct-current bus having a connected battery capacity of 1584 kw., also three converters of 5500-kw. total capacity not affected by the alternating-current disturbance.

At Crosby Street the brushes of a 4200-kw. unit were badly burned Connected to the same bus were 5000-kw. total in converter capacity and 480-kw. in battery capacity. The 4200-kw. unit at Van Dam Street against a 2500-kw. unit and 480 kw. battery, a 3500-kw. against a 3500-kw. and 1756-kw. battery at W. 41st Street, and a 4000-kw. against a 3500-kw.

and 2592-kw. battery did not give any signs of distress in opening on the alternating-current end by overload relays. Complete data on a number of such cases have been collected and in each case these general relations existed. It appears, therefore, that a critical condition exists when the capacity of the machine inverting is just equal to the capacity of the machine supplying the power to the inverted unit. When the capacity of the inverted unit is greater there is little chance that the machine will be damaged before the inverse time alternating-current overload device clears the unit. On the other hand, if the two capacities are equal trouble may result, and if the capacity of the inverted machine is less trouble may be expected and the amount of the damage depends to a large degree on the relative capacities. It should be clearly kept in mind that these conditions exist when certain relay arrangements are selected because of the operating conditions and the requirements that are desired. If reverse-current protection is provided on the direct-current end of the machine it appears that the machine can be successfully disconnected from the line before the unit is damaged under practically any condition of disturbance on the alternating-current end.

System Interconnections: Had the two alternating-current systems shown in Figs. 18 and 19 been connected together through suitable tie lines, the converters would have been protected against alternating-current disturbances.

The connecting together by tie lines of the alternating-current supply is usually a simple matter where a common frequency is used. If 25- and 60-cycle frequencies are used, a tie line cannot be employed and some other form of tie is necessary unless the 25- and 60-cycle converters are to make the only magnetic tie between the two systems. The synchronous-synchronous form of frequency-changer set is used to tie together systems of different frequency, but this form of tie does not connect the two systems together magnetically and, therefore, this form of tie (while it establishes a frequency tie) does not protect effectively the 25- and 60-cycle converters that operate in parallel on the direct-current end.

Booster converters are operated at unity power-factor under all conditions, while the field control converter is operated at a power-factor to give the required voltage. The

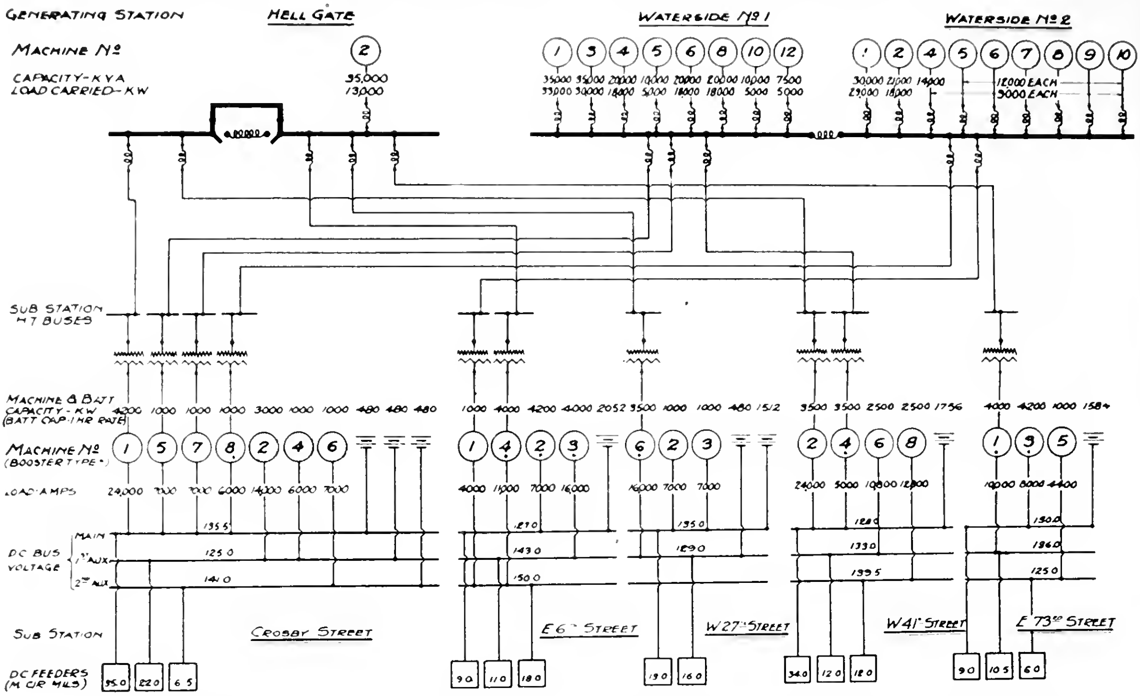

Fig. 18. Diagram of Connections of Converter Substation Fed from Two Independent Alternating-current Systems

Hell Gate generator lost its excitation. All converters fed from Hell Gate speeded up. Opened d-c. breakers. Brushes on 41st St. station synchronous converter entirely burned off (160 had to be replaced) shunt field may be under or over excited, and in cases where the direct-current end is not opened on reverse current a protective feature should be added to the field circuit that automatically establishes normal field when the overload alternating-current relay operates or when the oil circuit breaker opens for any cause. The device consists of a short circuiting contactor, a holding circuit, and on the rheostat a limit switch that drops the contactor when the rheostat has moved to the desired position.

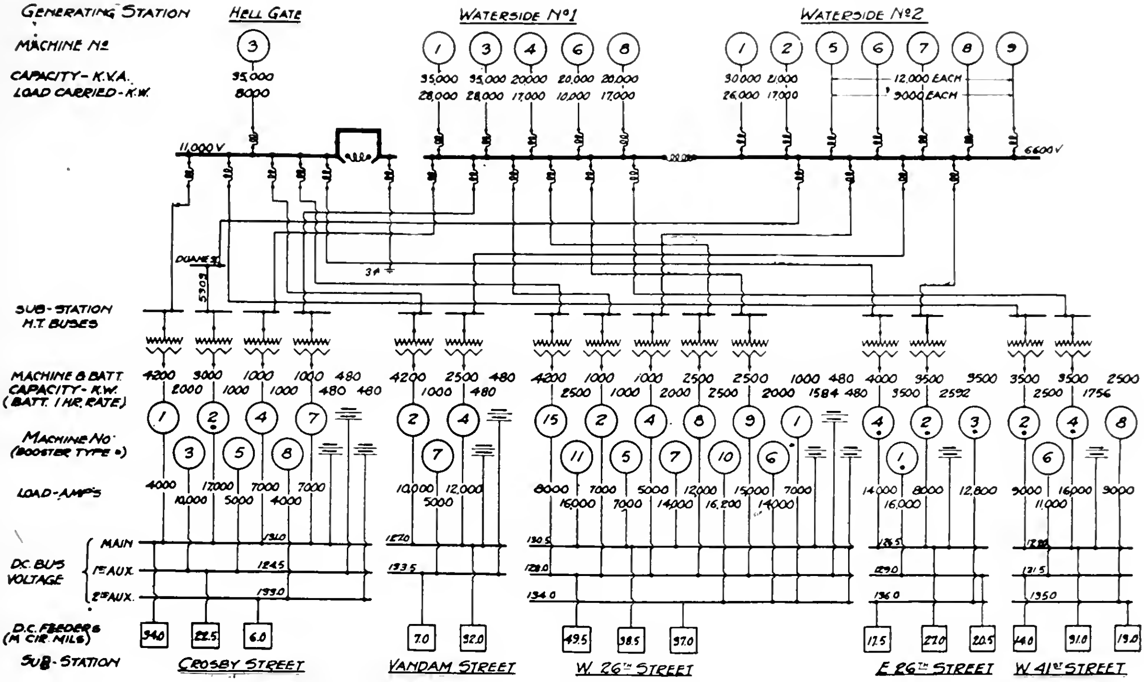

Fig. 19. Same as Fig. 18 Except for the Following Conditions:

Operator made a dead short circuit at 73rd St. station on feeder 7354. The Hell Gate end of this feeder opened by overload on W. 26th St. station. The oil switch opened automatically, also d-c. breaker on Crosby Street. Van Dam St., E. 26 St., and W. 41st St. converters unaffected. W. 26th St. and Crosby St. converters had brushes badly burned (practically all had to be replaced)

Motor-generator Set

In a motor-generator set the alternating-current and direct-current systems are completely isolated and, therefore, a disturbance in alternating-current voltage does not react directly on the direct-current system unless the voltage drops to a point that allows the motor to fall out of step and fail to deliver the necessary power to the generator, or unless the frequency changes sufficiently to cause the motor to act as a generator, returning power to the alternating-current system.

In the motor-generator set, it is entirely feasible to provide against a complete interruption of alternating-current power and allow the motor and generator to remain permanently connected to the two systems, and promptly upon the return of alternating-current power to deliver power to the direct-current system. Figs. 8a and 8b on page 417 show an oscillograph record of a complete interruption of alternating-current power and the restoration of this power shortly afterward. The input to the motor, the automatic control of the motor field, and the output from the generator are clearly shown. This scheme of operation reduces to a minimum the time required in restoring service on a direct-current system after alternating-current power is available.

RE-ENERGIZING AN EDISON SYSTEM

In the past the service of practically all the Edison systems of any magnitude has been protected by standby storage battery capacity. The battery served two principal functions; first, to supplement the generating capacity at times of peak load; and, second, to act as reserve capacity in case of an outage of the source of supply.

If an interruption in the source of supply is maintained for a time beyond the discharge capacity of the battery it is disconnected so that there remains sufficient capacity in the battery for energizing the system temporarily until the conversion apparatus can be connected. The momentary overload capacity of the battery allows for connecting the several substations in succession, which is a difficult problem in the case of conversion apparatus unless the voltage control is such that the output of any apparatus connected to the system can be controlled within safe limits. The amount of battery capacity in relation to system load varies widely and each operating company has established certain relations.

The problem of re-energizing depends on the capacity of the system, the number and capacity of the substations, the capacity and voltage range of the individual units in the substation, the standby battery capacity, and the distribution of the battery capacity throughout the system. The problem is most difficult in a large system without standby battery capacity because in such a case practically complete voltage control of the conversion apparatus is necessary. As has been pointed out, the voltage range of the synchronous booster converter is limited unless series resistors are used. The amount of system load, however, is a function of the voltage and it is not necessary to provide all of the conversion apparatus with approximately 100 per cent voltage range.

This situation has led to the consideration of a certain percentage of motor-generator capacity properly distributed throughout the system to serve as the first step in re-energizing and to bring the system to a voltage that can be approached by the synchronous booster equipment operating from a reduced voltage connection of the transformer and at maximum buck. At least 25 to 30 per cent motor-generator capacity would be required and it would be necessary to have a number of synchronous converter equipments running and ready to take load as soon as the system voltage was in reach of the converters, so as to reduce to a minimum the time that the motor-generators would be overloaded. In the average case the load on the Edison system is approximately equally divided between lights and power and it has been generally assumed that the current would vary directly with the voltage instead of at a rate determined entirely by the lamp characteristic, and it is on this basis that system requirements have been figured.

A careful study of each system is necessary to determine the best means for re-energizing. On certain systems it may not be economical to use motor-generator sets, and if such a system is not protected by standby batteries and the system load is such that sufficient converter capacity at the minimum obtainable voltage cannot be connected simultaneously to handle the situation, then load limiting resistors become necessary. There is at least one system that is proceeding on this basis at the present time.

On other systems the relation of a single substation capacity to system capacity is such that a sufficient number of converters can be connected simultaneously at the minimum voltage. The voltage is gradually increased as other stations connect to the system until maximum boost on the Y connection is reached. The transformer connections are changed, one at a time, allowing a further increase in system voltage until normal conditions are reached. Fig. 2 shows the voltage range obtained by a standard booster converter, and the reduced voltage connection on the transformer is made such that the converter operating from the running connection at minimum voltage can be successfully connected in parallel with the converter operating at maximum voltage and full load from the tap connection. For simplicity, the emergency running connection is also used as the starting connection and the starting characteristic of the converter is made suitable for this voltage. There are at least two companies operating moderate size systems without the standby battery capacity who plan to re-energize their systems by this method.

It is obviously desirable to provide the greatest possible voltage range of the synchronous booster converter, for re-energizing, that is consistent with successful operation under all conditions met with in re-energizing, and at the same time consistent with efficiency of operation under normal conditions. If the alternating-current voltage of the emergency running connection is less than 72 per cent of the rated voltage, then a larger booster is necessary to bridge the voltage gap than is standard for obtaining a 240- to 300-volt range. Commutation or stability may become limiting factors. Present experience indicates that the conservative allowable separation of the running and the emergency or starting connection is approximately 35 per cent.

Alternating-current Generators

By W. J. Foster

Alternating-current Engineering Department, General Electric Company

A well balanced, conservative design will give an alternator longer life and higher efficiency. The author discusses such questions as efficiency, temperature, stability and insulation and shows how these factors should be harmonized to make a satisfactory machine.—Editor.

"What is the largest alternator that can be built?" "What is the highest efficiency that can be obtained?" "What should be considered the reasonable life of an alternator?" "What is it possible to obtain in the way of long life, if designed particularly with reference to it?" These questions are often asked about alternators. While it is not possible to give absolute answers to such questions, some notes throwing light on these subjects may be of interest.

As to the size that is possible at the present time, this depends to a great extent upon the normal operating speed and the over-speed requirement that must be met. Let us confine our thought for the moment to 60-cycle generators. In the case of steam turbine machines, where the emergency governor is set to trip at 20 per cent over-speed; 40,000 kv-a. at 1800 r.p.m., with possibly 45,000 kv-a. at unity power factor, and 75,000 kv-a. at 1200 r.p.m., are being produced, or can be, if desired. In salient pole machines for coupling to water-wheels, where the over-speed is usually from 80 per cent to 100 per cent above normal, 50,000 kv-a. is about the limit for speeds as high as 450 r.p.m. At lower speeds, much higher capacity generators are possible. Assuming that transportation facilities can be provided, and a considerable part of the construction carried out at the plant, 150,000-kv-a. generators may be built at the present time at speeds of approximately 100 r.p.m.

Life of Alternators

In the matter of years of service that may be expected, a great deal depends upon the character of the service and the care that is taken with the machine. In the case of steam turbine generators, which are totally enclosed and, consequently, liable to operate at times when not in proper condition, due to the difficulty of inspection, and, furthermore, subjected to considerably higher temperatures in certain parts than other classes of a-c. generators, a certain life may be expected. In the case of salient pole generators of the most advantageous speed and voltage, twice as long life may reasonably be expected. By "life" in this connection, is meant the period from the time that the machine is first put into operation until a burnout or breakdown, that requires either the rewinding or rebuilding of the rotor or stator, occurs.

It is pretty generally agreed that the characteristic of an alternator which is most appreciated is freedom from little operating troubles. Undoubtedly sufficient attention is not often given to such matters as design of bearings and oiling arrangements to prevent the escape of oil, especially in the form of vapor, the design of collector rings for receiving the exciting current, and the design and construction of brush-holder mechanism.

Considerable thought is always given to the important features of the rotor construction. The best constructed rotors at the present time have provision for taking up shrinkages that may occur in the insulating material, either by easy adjustment, or automatically, which is far preferable. With a machine constructed throughout all its parts in accordance with the best principles of mechanical design, there remains the problems of forming up the copper for armature and field and of applying insulation of the proper kind and in the proper manner to secure the greatest possible freedom from trouble and the longest life.

Insulation

The insulation is of utmost importance. The more difficult problems are met in the insulating of the armature windings. It is the author's opinion that altogether too much emphasis has been laid upon the "looks" of new insulation and its ability to stand high potential test. It should be remembered that there are other qualities of even greater importance than the solidity of the newly formed insulation and the extremely high dielectric strength it possesses. Possibly the methods of testing and the intensity of the tests as now practiced are the best that can be suggested at the present time for the acceptance of new machines, but it is unfortunate that methods of testing insulation have not been established of such nature as to impose tests everywhere throughout that correspond

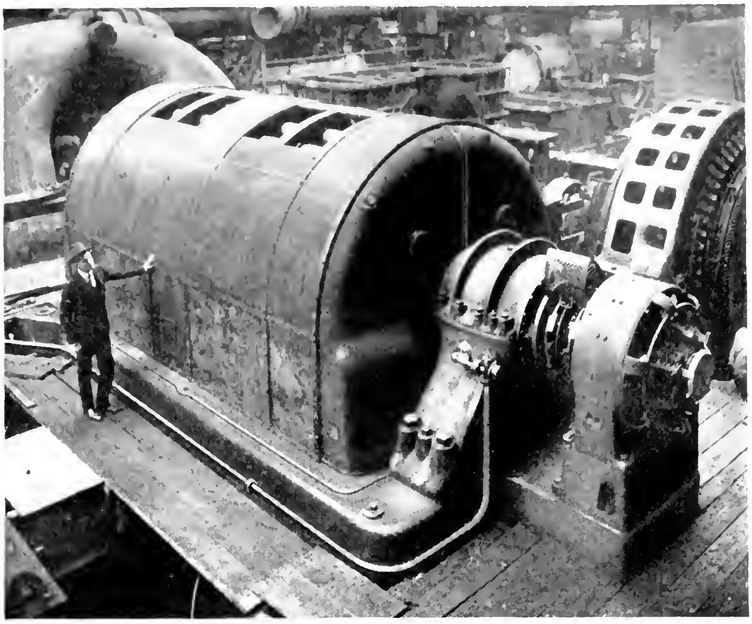

Fig. 1. 35,300-kv-a., 60-cycle 13,200-volt 80 Per Cent Power-factor 1800-r.p.m. Steam Turbine Generator for Union Gas & Electric Co., St. Louis. The first machine of this rating has been in operation since January, 1922, in the Calumet Station of the Commonwealth Electric Co., Chicago. Twenty-one have been or are being built in the Schenectady Works

developed that is too hard and unyielding for coils of wire that cannot be perfectly embedded in rigid containers throughout their entirety.

The present high test encourages insulation engineers to concentrate their efforts on the development of materials of the highest possible dielectric strength per unit thickness on the parts of the windings that are embedded in the slot. In order to have a corresponding dielectric strength at points a few inches removed, it is necessary to thicken the insulation materially, especially at the bends. The amount of "padding up" is determined by the weak points that are discovered when the high tests are applied. Who knows how much better, viewed from the standpoint of long life and freedom from trouble, windings might be made and to the dielectric stresses that occur when the machine is in actual service and passing through its complete cycle of operation. The high potential test now standard is based on consideration of the windings, either as a whole or in sections, as condenser plates. The intensity of the test is measured not by the dielectric stresses that exist in practice as between turns in the same coil, coils in the same or other phases, but solely on the potential generated at the terminals of the several phases. Granted that there should be a rigid test, one that allows a good margin of safety above what is expected in service, it is obvious that to require too high a test is to court troubles later, due either to the unnecessarily thick insulation or to a type being

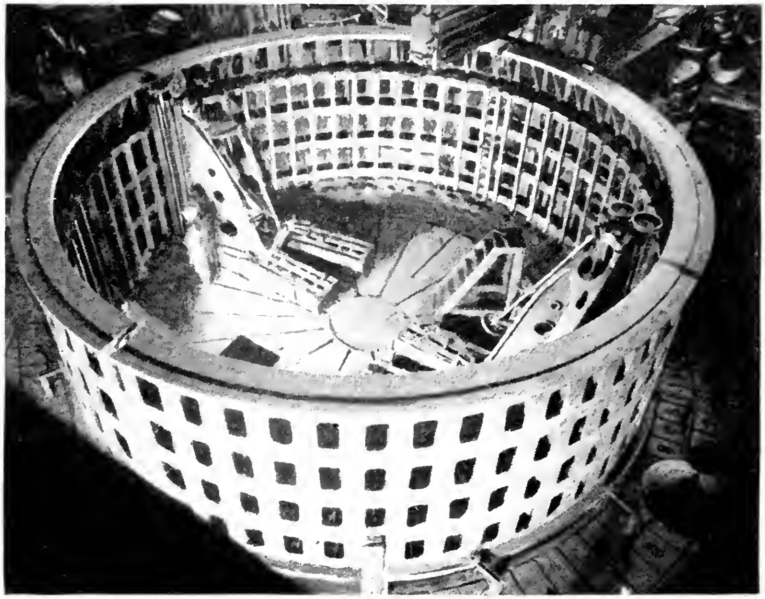

Fig. 2. Stator Frame of 65,000-kv-a., 107-r.p.m., 25-cycle, 80 Per Cent Power-factor, 12,000-volt Vertical Generator (on 60-ft. Boring Mill) for Niagara Falls Power Co. The immense size of the casting made impossible the taking of a photograph which does not show distortion.

insulated if the present high test were reduced, granted that it is now unnecessarily high? It is significant that some machines are now in use that were built many years ago for certain voltages and reconnected later for higher potentials, usually double potential, or 1.73 times the original, with insulation that no manufacturer would trust to stand the high potential tests now standardized for the higher voltage.

A valuable quality in insulation is repairability. While every effort should be put forth to design and build machines that will not require repairs for a long period, accidents may occur and repairs to the windings be necessary. It is then of great value that the insulation be of such character as to remain in close contact with the copper at all points so as to permit the neighboring coils to be bent and distorted while being removed and replaced in making the repairs. Radial slots are still the order of the day. A particularly objectionable type of insulation, when it comes to repairs, is that which, in service, springs away from the copper at the middle of the sides just beyond the ends of the core, or where the coil spans ventilating ducts. This tendency is more pronounced with the deep slots of present day design than with the more shallow slots of former days.

Stability of Alternators

A characteristic that should be incorporated in practically all a-c. generators is ability to remain in step at sudden overloads incident to disturbed conditions, due to grounding of line, mistakes in switching, etc. This characteristic is designated "stability." The usual way of studying this characteristic is to draw curves showing, first, the volts and amperes output and, second, the kv-a. output and amperes that the generator will deliver with excitation held constant. Fig. 3 shows typical external characteristics at 80 per cent power-factor (normal excitation) of six generators with short-circuit ratios covering the range 0.9 to 1.5. The short-circuit ratio is obtained by dividing the ampere turns required to give normal volts on open-circuit, by the ampere turns required to produce normal current on short-circuit. These curves represent actual designs.

Similar curves might be drawn for the same generators at other power-factors, such as 90 per cent or unity. The design should be such that the working point is to the left of the peak of the output curve and slightly removed. It should not be at the crest or to the right. Short-circuit ratios ranging from 1.0 to 1.25 give machines that are quite satisfactory in the matter of stability. A drop in voltage is what occurs when there are disturbances on the system that call for temporary assistance. A stable generator is one that can carry increased load at reduced voltage without increase of excitation.

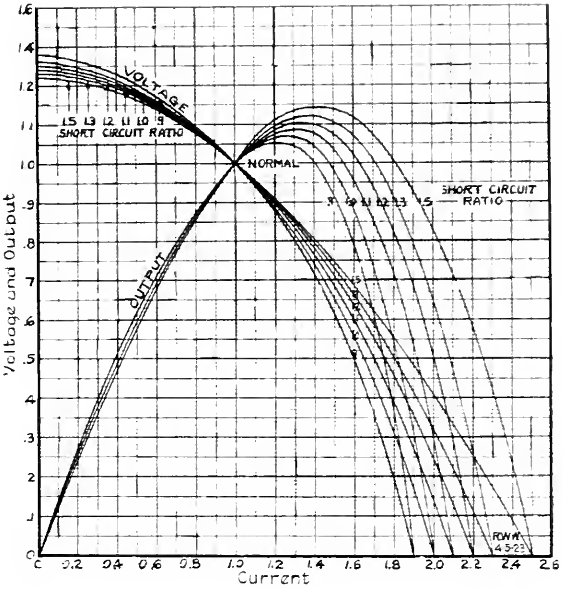

Fig. 3. External Characteristic Curves of Salient-pole 80 Per Cent Power-factor 60-cycle Alternating-current Generators. These curves are based on machines of average reactance of 20 per cent and average degree of saturation

It is desirable in alternators in large systems to have as high reactance as is consistent with such characteristics as stability, in order that the instantaneous rush of current in case of a short-circuit in operation may be kept down. The value of this current is often given in terms of the rated current. This ratio should not be confused with the short-circuit ratio as discussed in connection with stability.

Economic Voltage

The question is often asked in connection with new installations "What is the best voltage to adopt?" An unqualified answer should not be attempted. It sometimes happens that the high voltage is the best, due to the possibility of obtaining better all-round characteristics in the generator. This is true in the case of two-pole generators of the largest output in steam turbine units. The number of circuits per phase is limited to the number of poles; hence, only two circuits are possible. In such large machines a single turn generates something in the order of three-hundred volts. A good machine cannot be built without having a large number of slots to keep the amperage per slot within certain limits. The result is that a very few turns per coil, say one or two, will produce the full voltage. If a much lower voltage were insisted upon, the only way of obtaining it would be to reduce the number of slots greatly and accept the additional losses and higher temperatures due to the losses incident to the high amperage per slot. There is also a serious objection to lower voltage machines in the case of these large capacity two-pole generators, due to the difficulty of making connections between coils of such great cross section of copper. As a rule, such limitations in the choice of potential as the above do not occur in waterwheel-driven generators of the largest capacity. The limitation may occur if certain speeds are insisted upon in connection with large generators of any given periodicity; for example, a speed of 124 for 60-cycle generator requires 58 poles and gives only two choices as to the number of circuits per phase, 2 or 29. Twenty-nine circuits would be almost prohibitive, by reason of the complications in connections and the large number of turns per coil; hence, practically the same limitations exist as in a two-pole steam turbine generator when the number of poles is such that the factors are 2 and a prime number of large size, such as 29.

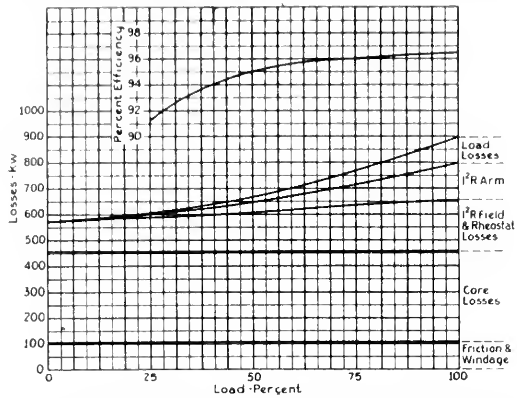

Fig. 4. Characteristics of a 31,250-kv-a., 60-cycle, 13,200-volt, 80 Per Cent Power-factor 150-r.p.m. Generator. Designed to meet the usual specifications for a first-class generator where advantage is taken of temperature rises of 50 deg. C. by thermometer and 60 deg. C. by embedded detector

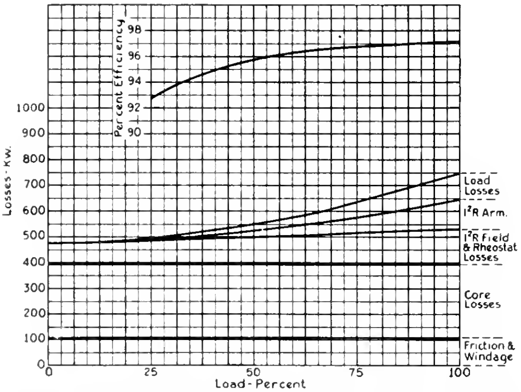

Fig. 5. Characteristics of a 31,250-kv-a., 60-cycle, 13,200-volt, 80 Per Cent Power-factor 150-r.p.m. Generator. Designed for high efficiency where the temperature rises will be much below the allowable 50 deg. C. by thermometer and 60 deg. C. by embedded detector

As a rule, in connection with waterwheel-driven generators of large size, pressure is brought to bear from outside, to use the highest voltage, viz., 13,200, on account of the saving in cost in the station wiring, switches, etc. Throwing such considerations aside, it is the author's opinion that an intermediate voltage, preferably 6600, is the best for the largest capacity generators, inasmuch as the electrical design can be made superior, due to the increased number of slots, the reduced size of the coils and the thinner insulation. It may be expected that the efficiency will be a little higher and the life a little longer. Machines of 6600 volts are seldom subject to any deterioration of insulation on terminal coils, due to corona, whereas 13,200-volt machines in certain localities, especially at higher altitudes, are often subject to a certain amount of damage. Fortunately, it is possible in many cases to escape the objection to switches of great capacity, by running generator leads direct to the low side of step up transformers and by doing the switching on

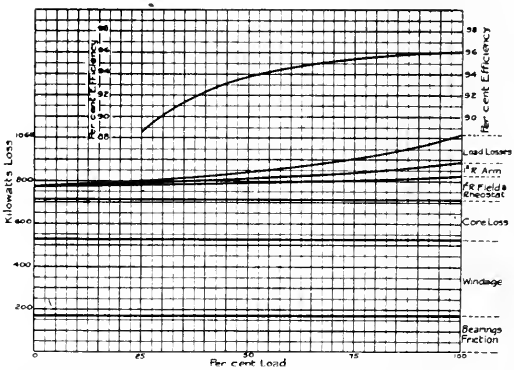

Fig. 6. Characteristics of a 31,250-kv-a., 60-cycle, 13,200-volt 80 Per Cent Power-factor, 1800-r.p.m. Steam Turbine Generator. The windage loss is large. The losses in the steam turbine generator are relatively different from those in a waterwheel generator; see Figs. 4 and 5

the high side. Fortunately, such speed as 124 r.p.m. may, as a rule, be avoided, as most waterwheel builders can adapt their designs, without much loss, to a speed of either 120 r.p.m. or 128½, in the case of 60-cycle generators, and thus make it possible to use a number of circuits that will allow a good 6600-volt winding to be developed.

Efficiency

The importance of high efficiency is becoming more generally recognized. At the same time, competition in securing orders has a tendency to make designers go closer to the limits of allowable temperature rise, which tends in most cases to detract from the high efficiency that would otherwise be possible. In most waterwheel-driven generators very high efficiency is a fine investment for the purchaser. He can well afford to pay the higher price. Such high efficiencies almost invariably mean low temperature rise. Instead of going to the limit of 60 deg. C. or 80 deg. C. rise by the embedded detector, it is often the best engineering not to go higher than 40 deg. C. Fig. 4 shows segregated losses and efficiency of a 31,250-kv-a., 150 r.p.m. generator, designed, in competition, to meet standard specifications in the matter of temperature rise, while Fig. 5 shows segregated losses and efficiency of a generator designed for highest efficiency at greater cost.

Fig. 7. Stator of the 20,000-kv-a., 257-r.p.m., 60-cycle, 11,000-volt Horizontal Generator, City of San Francisco Hetch Hetchy Development

The two generators have practically the same characteristics in other respects, reactance, stability, flywheel effect, etc. But the more efficient has an armature core of the best grade of silicon steel and a greatly increased quantity of copper in both armature and field. It is an easy matter for any user of such machines to calculate the value to him in dollars and cents on the original investment of the higher efficiency generator. He cannot determine accurately the greater value of the low temperature machine that will result, due to its longer life. It is generally agreed that a machine with the lower temperature will have its insulations remain in first-class condition longer than the one with the higher temperature.

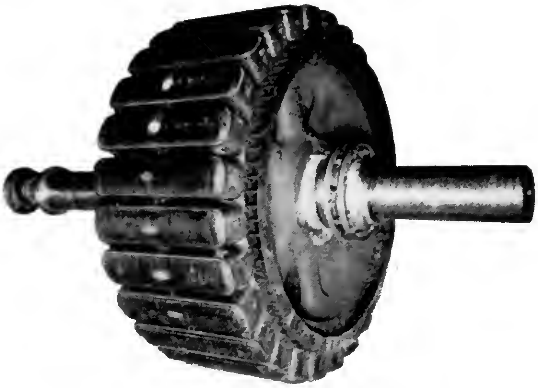

Fig. 8. Rotor of the 20,000-kv-a., 257-r.p.m., 60-cycle, 11,000-volt Horizontal Generator, City of San Francisco, Hetch Hetchy Development

Fig. 6 shows a corresponding efficiency curve for a 31,250 kv-a., 1800-r.p.m. steam turbine generator. It will be seen by referring to this curve sheet, that the greatest loss is the windage; furthermore, that the load losses are also high. This particular generator had its armature core built up of the best grade of silicon steel so that it does not seem possible at the present time to obtain any reduction in core losses. In like manner, the armature slots are as large as is consistent with lowest aggregate losses, while the rotor contains all the copper possible. Hence, there appears no way of reducing the I^2R of either armature or field. These reductions would affect the efficiency but little in comparison with the effect that might be obtained if it were possible to greatly reduce the windage and the load losses. It now appears possible by certain niceties in design, to considerably reduce the load losses.

Isolated Phase Arrangement of Switching Equipment

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This article is the first that we have seen which fully describes the "isolated phase" construction for switching equipment, and which explains the merits of this system. The vertical and horizontal construction are discussed and illustrations shown to emphasize the points made in the text. Attention is called to the fact that, when the phases are isolated, phase to phase short circuits will be eliminated.—Editor.

The advent of the super-power station with its concentration of power has necessitated that special consideration be given to the design of its switch house, in order to eliminate the probability of bus short circuits. By locating the three phases of the bus, each with its corresponding switching and protective equipment in compartments isolated from each other by firewalls, and connecting all circuits to the bus through reactors located in the same manner, a logical way of eliminating short circuits between buses has been obtained.*

While in this article the application of isolated phase switch gear is discussed in its relation to the super-power station it is not the intention to limit its use to stations of large capacities. In general it may be said that its application depends upon the use of reactors, the type of oil circuit breaker used, the number of circuits and local conditions. In every case the choice of design can be made only after careful analysis of the problem.

There are two natural ways in which the phase may be isolated: first, with the corresponding equipment of each phase on the same floor and vertical firewalls between the phases as shown in Fig. 1. This is called horizontal

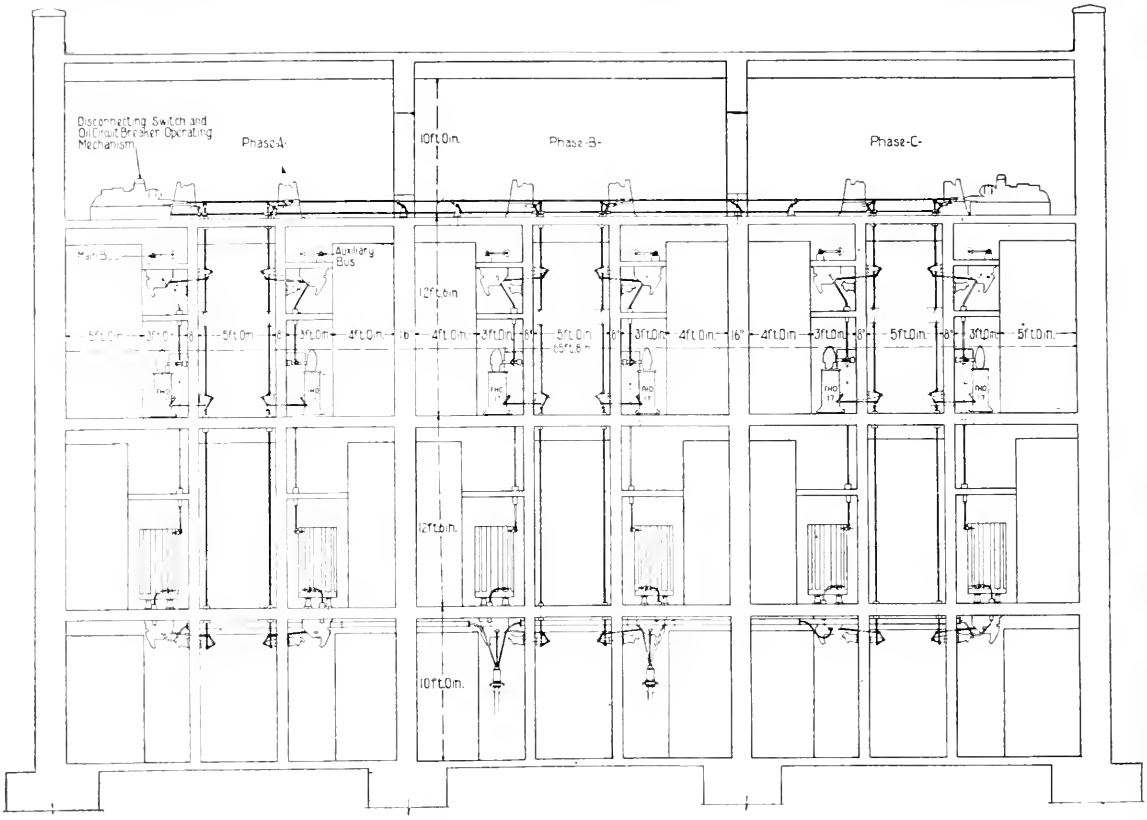

Fig. 1. Section of Horizontal Isolated Phase Switch House

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* This design was first proposed by B. G. Jamieson, of the Commonwealth Edison Co.

phase separation. The second way is to locate the equipment for each phase on a separate floor as shown in Fig. 2. This is called vertical phase isolation.

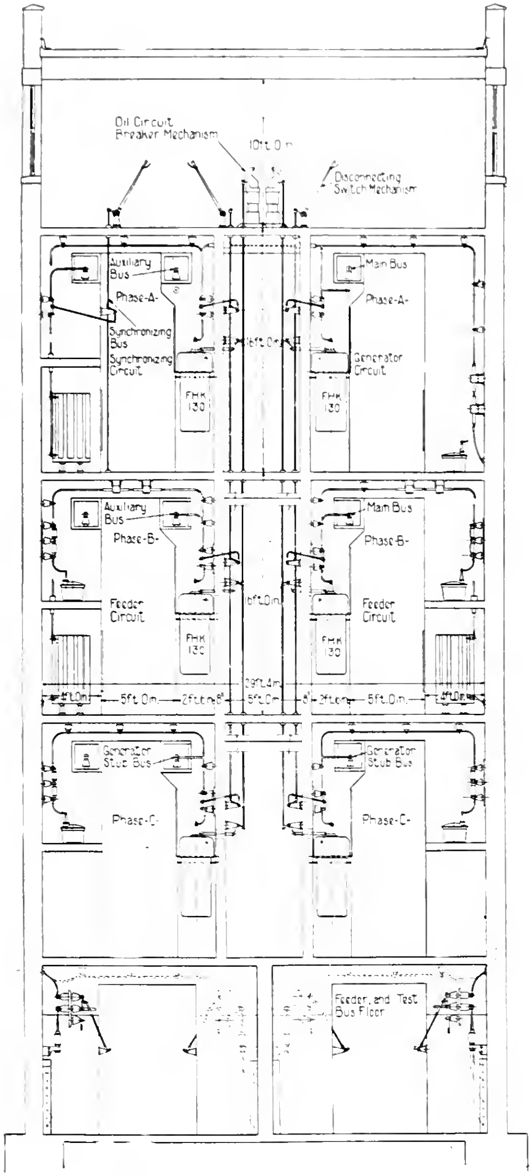

Fig. 2. Section of Vertical Isolated Phase Switch House

Horizontal phase separation inherently requires a greater ground area than the vertical arrangement and as stations are usually located where land is valuable, this factor has considerable influence on the choice. Moreover, the switch operating mechanism for the horizontal phase separation is more complicated and expensive than that required for vertical phase separation. Horizontal phase separation has several desirable features. For example, similar equipment may be located on the same floor, and the circuits terminate in a cable room directly below the reactors thus making a short run, as shown in Fig. 1.

Vertical phase separation inherently requires a building of considerable height. This is not objectionable from an architectural or constructive standpoint as the adjacent buildings in the group, including turbine room and boiler house, have considerable height and the switch house can be designed to present a similar external appearance. From the comparisons made of various layouts, it has been found that the vertical phase separation requires less cubical content of building than the horizontal phase separation. The space occupied by oil circuit breakers and reactors is practically the same for both. The saving in building space is therefore in the mechanism and cable rooms. This is evident when one considers that with the horizontal arrangement the operating mechanism must extend over the three phases of the oil circuit breakers, and that the width of the cable room is governed by the width of the circuit breaker rooms. On the other hand, with the vertical arrangement, the operating rods and bell cranks are located on the vertical walls of the mechanism aisles and the cables are dropped from the several floors through conduit located in the wall directly into end bells in the cable room below.

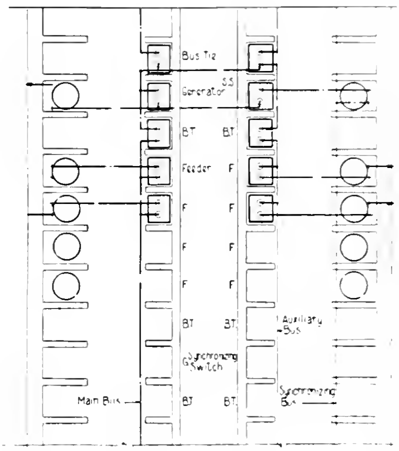

Fig. 2a. Plan of Switch House Shown in Fig. 2

The application of horizontal phase isolation to switch house design may in some cases be found advisable and practicable, but in general it may be said that our experience has shown that vertical separation is less expensive, more flexible and better adapted to complicated layouts. In this article, we shall therefore confine our discussions primarily to vertical phase separation.

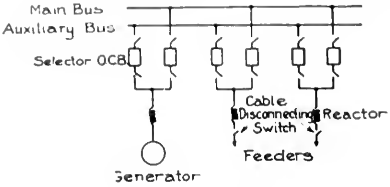

Fig. 3. One-line Diagram

Examples of Typical Layouts

To illustrate the simplicity of the isolated phase arrangement, as compared to the conventional three-phase arrangement with the three phases located in adjacent compartments in the same room, and the three phases of the oil circuit breaker mounted as a unit, let us consider several one-line diagrams that are typical of arrangements used by some of the large operating companies.

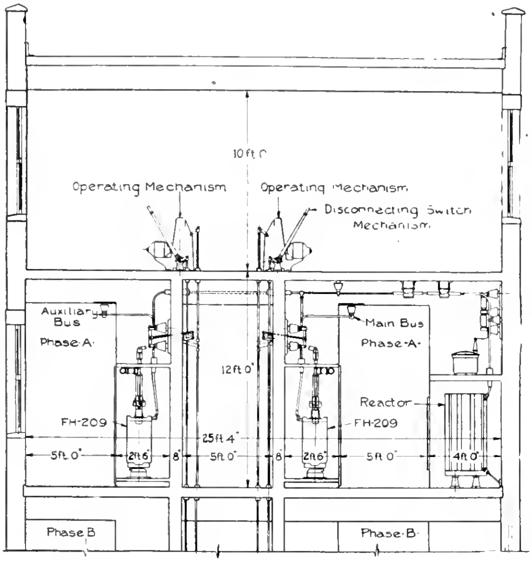

Fig. 4. Section of Vertical Isolated Phase Switch House

In Fig. 3 is shown the simplest circuit that should be considered for a large central station, namely, a double bus with selector oil circuit breakers and reactors on the generator and feeder circuits. In Fig. 4 a plan and section of the vertical isolated phase switch house, corresponding to this arrangement of equipment is shown.

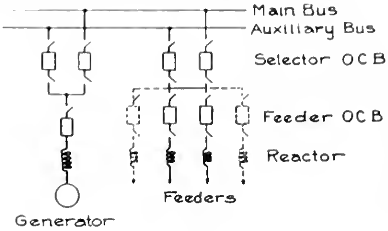

Fig. 5. One-line Diagram

In Fig. 5 is shown a one-line diagram of a complicated but very common type of circuit. The feeders have reactors and are grouped with two selector switches for each group of two or more feeders. Each generator circuit has a main oil circuit breaker, two selector oil circuit breakers and a reactor. Thus there are two breakers in series in every circuit. In Fig. 6 a section of vertical isolated phase switch house corresponding to this arrangement of equipment is shown.

In Fig. 7 is shown a one-line diagram of a more complicated and very flexible and efficient circuit. Each feeder has a single oil circuit breaker and reactor. Four feeders are grouped together on each section of bus. Two selector oil circuit breakers are provided for each group bus. These breakers are interlocked so that either one, but not both, can be closed, thus connecting the group bus to either of the adjacent generators. Each generator is connected through a reactor and oil circuit breaker to a synchronizing bus and also through another oil circuit breaker to a stub-bus which can be connected to any

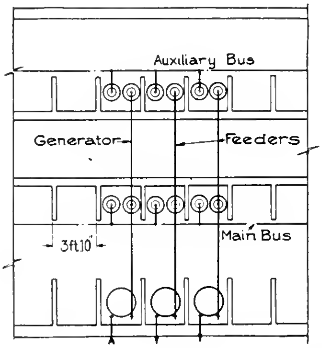

Fig. 4a. Plan of Switch House Shown in Fig. 4

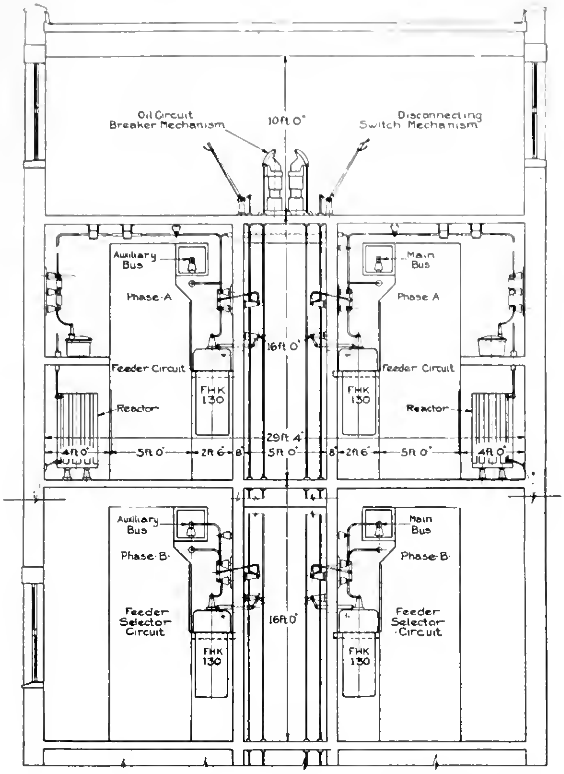

Fig. 6. Section of Vertical Isolated Phase Switch House
Upper Floor Section AA
Lower Floor Section BB

combination of four bus sections. In Fig. 2 a section of a vertical, isolated phase switch house corresponding to this arrangement of equipment is shown.

In Fig. 8 is shown a very complicated diagram of connections. This consists of double ring busses with reactors between the sections of each bus. Each bus section can again be divided by an oil circuit breaker. Each half section will have connected to it one generator, a number of feeders and a connection to a common transfer bus. The feeders and generators will have both main and selector oil circuit breakers. In Fig. 9 a section of a vertical, isolated phase switch house corresponding to this arrangement of equipment is shown.

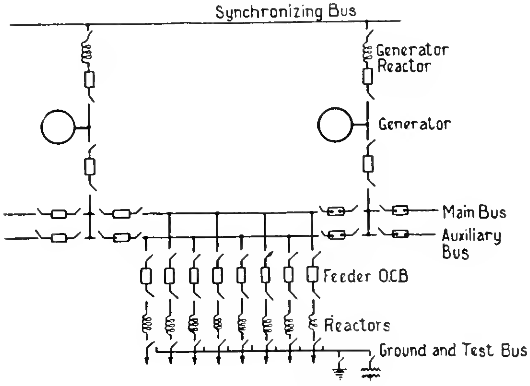

Fig. 7. One-line Diagram

Reviewing the sections of switch houses shown in Figs. 2, 4, 6 and 9, it should be noted how simple the design of station becomes when vertical isolated phase arrangement of equipment is used, regardless of the complications introduced in the system of connections. The diagram shown in Fig. 3 is quite simple and probably would not find application in the larger stations but it is a typical diagram used by many of the moderately large stations throughout the country. The application of isolated phase to this arrangement is, however,

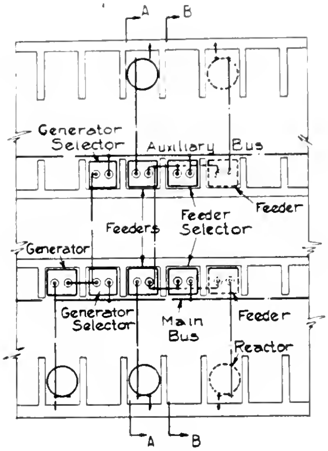

Fig. 6a. Plan of Switch House Shown in Fig. 6

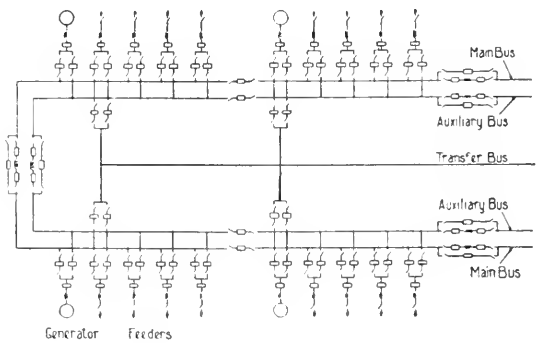

Fig. 8. One-line Diagram

desirable and warranted for the following reasons:

1. Bus short circuits practically eliminated
2. Short circuit stresses reduced
3. Space occupied the same or less
4. Connections shortened and crossing of phases eliminated
5. Connections easily changed
6. Structure adapted to any type of oil circuit breaker
7. Arrangement of reactors improved
8. Operating mechanisms removed from proximity to oil circuit breakers
9. Disconnecting switch mechanisms easily mechanically interlocked with mechanism of oil circuit breakers

The diagram shown in Fig. 5 is one that will probably find more general application in large stations as it uses two or less oil circuit breakers per feeder and at the same time has the advantage of two breakers in series. The connection shown in full line on the feeder circuits represents the familiar so called "H" connection which is used extensively by a number of large operating companies. By the addition of the circuits shown in dotted lines, this connection becomes the so-called group bus. This is also used by a number of companies and has the advantage of a fewer number of oil circuit breakers per feeder with only a slightly less reliability of operation. With this combination of switching equipment the advantages of isolated phase arrangement become more evident. A comparison of the arrangements pictured in Figs. 4 and 6 show the same arrangement of building, i.e., a double row of circuit breakers per floor, similar location of bus, reactors and operating mechanisms, and while different types of oil circuit breakers are shown in the two arrangements and dimensions of compartments are different, either breaker is applicable to either arrangement, dimensions changing accordingly.

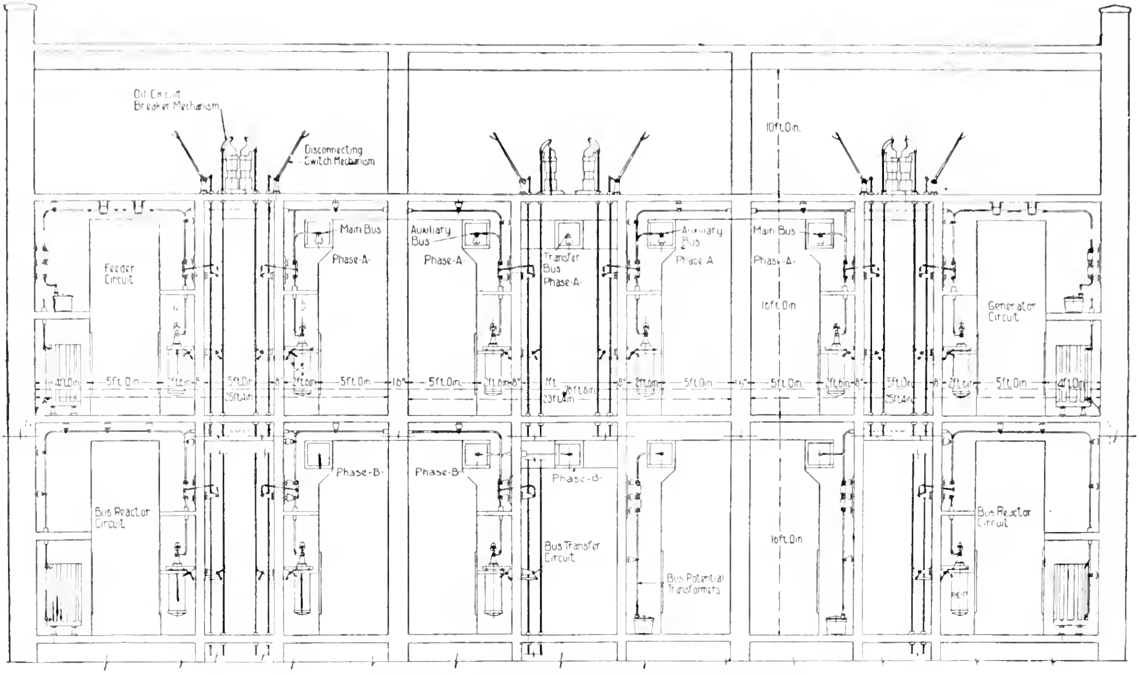

Fig. 9. Section of Vertical Isolated Phase Switch House Upper Floor Section AA—Lower Floor Section BB

The designs shown in Figs. 2 and 9 have been included to illustrate that isolated phase arrangements can be applied to the most complicated circuits without introducing features other than an additional row of breakers or a bus or two. It should be noted that the general arrangement of equipment is very similar for all one-line diagrams as illustrated in Figs. 2 to 9 inclusive.

We have not attempted to show designs of switch houses using the conventional three-phase arrangement of equipment for one-line diagrams shown in Figs. 3, 5, 7 and 8 but will leave this for the reader to visualize. The complications involved in obtaining a design that is comparable even for the simple circuit shown in Fig. 3, where reactors are used on all circuits, are sufficient to require a building of the same or even greater dimensions. With circuits such as shown in Figs. 7 and 8 the complications of buses and connections become so involved that it is quite evident that the isolated phase design will require less space and a simpler structure, and provide better operating conditions.

Building

The number of circuits installed in the switch house of a large power station warrant that special consideration be given to the building housing this equipment. In general it is found desirable to locate this building independent of the main power plant. This depends, however, on local conditions and it may be preferable to build it as a section of the power house. In either case an isolated phase design is applicable.

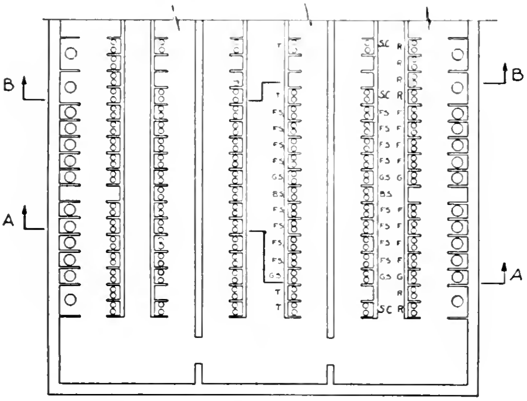

Fig. 9a. Plan of Switch House Shown in Fig. 9

The external appearance of this building, or section of building, should correspond architecturally to the power house. This may govern to some extent its overall dimensions. The building should house not only the main switching equipment, but also the switching and control equipments for the many auxiliary power circuits required for the station service. This latter equipment may take up as much or even more space than the main switch gear.

Isolated phase switch houses introduce no new features in building construction although in their design it would be highly desirable to eliminate all steel work were such construction feasible. Re-enforced concrete buildings have some desirable features which those framed with structural steel do not possess.

The location of the different phases on separate floors must necessarily have some effect on the steel framing of the building. Sections of this framework form loops around the separate phases causing hysteresis and eddy current losses in themselves. Other sections of the steel work form loops parallel with the buses which result in currents being induced in them.

Troubles from hysteresis may be eliminated to a large extent by installing copper bands around all members of vertical loops at right angles to the busbars.. Troubles due to induced currents in the steel members, which would probably be encountered only in the joints, can be corrected by bonding the latter.

Re-enforcing steel in barriers and walls in close proximity to conductors should be eliminated as much as possible, and when used must have sufficient cross section to carry, for a limited time, the current that will flow on a short circuit to ground. This rules out the use of wire mesh or metal lath for re-enforcing and calls for steel rods of appreciable cross section. These rods must be well bonded together and well grounded at as many points as possible.

Aisles and Cross Aisles

In addition to having the phases located in separate rooms isolated by fire walls it is also desirable to have the main and auxiliary buses and also the several oil circuit breakers on the same circuit in rooms separated by fire walls. The isolation of reactors from circuit breakers may also have some merits; this, however, requires another operating aisle and whether the advantage gained warrants the increase in width of building will depend on the space available for building and the scheme of connections. If bus reactors are used it would not be economical to put them in a separate room from the bus to which they connect. It is therefore questionable whether the isolation of reactors warrants the expense incurred. In Figs. 2, 4, 6 and 9 we have shown reactors in the same rooms with oil circuit breakers, and this has been found to give a very satisfactory arrangement of equipment and also a minimum width of building.

The location of operating mechanisms for the oil circuit breakers and disconnecting switches in the same compartment as the equipment introduces a hazard and is objectionable. It also necessitates openings in the floors between phases which permit communication of trouble. It has therefore been found advantageous to arrange the adjacent rows of oil circuit breakers back to back with an aisle about 5 ft. wide between the compartment walls and to install in this space all the operating rods, bell cranks, etc. Operating mechanisms for oil circuit breakers and disconnecting switches have been adapted to this arrangement and a very simple and compact arrangement of mechanisms obtained. Operating rods are thus located remote from live parts in a position where they can be readily installed and adjusted without the need of entering oil circuit breaker rooms. The introduction of this aisle has simplified the problem very much and also increased the advantages of isolated phase station design. Conduits for instrument transformer leads can be run in this mechanism aisle and not buried in concrete, thus making them more accessible. The use of armored cable for instrument transformer leads is well adapted to this arrangement and would no doubt simplify the conduit system of the station. This aisle also provides space, isolated from live parts, for air shafts for the ventilating system of the station.

Cross aisles and transverse fire walls should be provided to isolate groups of equipment. The location of these will usually be governed by the number of generators or sections of bus. These cross aisles should be of sufficient width to remove equipment. It is also desirable that elevators and stairways be located at these cross aisles to facilitate access to all floors and also removal of apparatus.

The aisles in the oil circuit breaker rooms should be liberally designed to permit inspection and removal of the equipment. The elimination of hand operated disconnecting switches, however, removes a limitation encountered in the three-phase arrangement and the width of these aisles may be encroached upon without introducing hazards in the operation of the station.

The vertical phase isolation inherently requires a narrow building, so that liberal spacing can be given to the aisles, and may even be found necessary in some cases to obtain correct architectural features for the exterior of the building.

The use of windows in isolated phase switch houses is questionable except at the cross aisles. They admit light only to the outer aisles and artificial illumination is necessary in all others; furthermore, if windows are installed space must be left in front of them in which equipment cannot be placed and is therefore of no value. Again the cable ducts are generally run in these outer walls and windows would interfere with them. Windows are more of a detriment than an aid in the ventilation of the building since stations of this type require an artificial ventilating system, using blowers, either forced or induced, so that the opening of these windows would destroy the effectiveness of the ventilating system.

The system of illumination used in the cross aisles, mechanism aisles, etc., can be in accordance with the general practice, but in the oil circuit breaker rooms exposed fixtures should be eliminated and ceilings recessed at the outlets to form reflectors for the lighting units. Moderate sized lamps should be used and the spacing should be such that the compartments are well illuminated in order to facilitate inspection and repair of apparatus.

Control Room

The control room should be located adjacent to the mechanism floor of the building in order to facilitate access to the operating mechanisms and the disconnecting switch levers. This location also has the advantage of shortening the length of the control circuits to the breaker mechanisms, and the secondary leads to the instrument transformers. As the space above the breakers in the mechanism room is all occupied, and since the control room should have a room below it for terminating conduits, this control room may be conveniently located above the section of building taken up by the station service equipment. If this location is not possible the center section of the building can be carried up two floors above the mechanism floor, and thus room provided for terminating the conduit and installing the control equipment.

Cable Room

The number of feeder cables radiating from such a switch house as we are considering warrants provision being made for a cable room in which to terminate the connections from the separate phases at the end bells of the three-conductor lead sheath feeder cable. A flexible system of arrangement of feeder cable ducts should be provided so that the cable may terminate at a point in the duct line directly below the breaker to which it connects. By properly designing these runs of conduit the changing over of a cable from one section of the bus to another, at some future date, may be greatly facilitated.

Buses

In the conventional three-phase arrangement of buses, where they are in close proximity to each other, the need of enclosing them in concrete compartments is evident. In an isolated phase arrangement, however, the separate phases of the buses are entirely remote from each other and the use of a bus covered with insulation may be considered instead of one run in a compartment. This compartment at best must be opened at every oil circuit breaker so that little advantage is gained, and considerable expense and inconvenience encountered, by its use. All of our high interrupting capacity oil circuit breakers are vented and there should be no throwing of oil which would affect this bus. Attention is called to the ease with which such a bus as shown in Fig. 4 can be installed and inspected. Considerable saving in the cost of bus supports is experienced in the use of isolated phase design, due to the limitation of the possible short circuit current and the elimination of magnetic stress between phases.

Connections

For circuits carrying heavy currents bar connections must necessarily be used; however, where feasible, insulated cable connections with long radius bends are preferable. Due to the liberal spacing obtained the magnetic stresses between adjacent conductors are materially reduced and special extra heavy duty supports are not in general required. Only where the circuits form loops or where sharp bends must be made is it necessary to give special consideration to the supports.

Disconnecting Switches

In all isolated phase arrangements the disconnecting switches used to isolate the oil circuit breakers have been made gang operated from a point remote from the switch aisle (usually the mechanism room) and have been interlocked with the mechanism of the oil circuit breaker in such a manner that they cannot be operated except when the oil circuit breaker is open. While this feature is necessary in isolated phase construction it by no means belongs to isolated phase exclusively. It is a feature which should be incorporated in any design where large amounts of power are involved. This is due to the fact that the operation of such disconnecting switches should be at a point remote from the oil circuit breakers and should be interlocked with the oil circuit breaker mechanism. There are instances on record where, after a heavy short circuit in a switch house of conventional three-phase construction, it was twenty minutes before the operators could get into the switch room to operate the disconnecting switches necessary to resume operation.

The disconnecting switches used to isolate the oil circuit breakers are usually operated in gangs of six, three on each side of the oil circuit breaker. By locating the operating handles on the mechanism room floor they are made remote from the breakers themselves, easily interlocked with the oil circuit breaker mechanism, and usually in a convenient location for operation. Means should be provided to lock the disconnecting switch mechanisms in the open position in order that they shall not be operated, except by the proper person when the equipment is isolated for repairs. The disconnecting switches for isolating the oil circuit breakers are most conveniently mounted on the back wall of the oil circuit breaker compartment. The operating rods for these disconnecting switches are placed in the mechanism aisle.

The disconnecting switches used to isolate the outgoing cables may be made either of isolated phase or of the conventional three-phase arrangement since they are on the outgoing side of the reactor. They may be operated either by a remote hand operated mechanism, if it is desired to interlock them with an oil circuit breaker, or they may be operated by levers located adjacent to them. These switches may be operated single-pole or three-pole. It is generally more convenient to locate these disconnecting switches in the cable room.

The disconnecting switches themselves are of two kinds, the lever type, and the brush type. The lever type is the common form of disconnecting switch. The brush type was designed primarily for a special case where it was desired to have the disconnecting switches operated automatically by the oil circuit breaker mechanism, in such a manner that they are closed before the oil circuit breaker is closed and opened with a certain time delay after the oil circuit breaker opens.

Remote operated disconnecting switches do not need to be equipped with safety catches since they are held closed by their operating mechanisms.

If it is desired to ground the equipment for inspection or repairs the disconnecting switches can be made double-throw and one of the clips used as a grounding clip. In the brush type disconnecting switch the grounding contact is made of the wedge and finger type.

Oil Circuit Breakers

Practically any oil circuit breaker in which the different phases are located in separate tanks can be adapted to isolated phase arrangement, but it has not yet been thought desirable except on those of higher interrupting capacity.

The following is a list of oil circuit breakers which may be considered for isolated phase designs, with their interrupting capacities in amperes at 15,000 volts.

Type of Oil Circuit Breaker	Interrupting Capacity
FH-103	10,000
FH-203	14,000
FH-206	20,000
FH-209	30,000
FHD-17	34,500
FHD-21	58,000

Type FHK-130 (tank type) oil circuit breakers can also be furnished for the same range of interrupting capacities in amperes at 15,000 volts.

The Type "FH" oil circuit breakers, namely the FH-103, FH-203, FH-206, FH-209 are similar to the familiar FH-3, FH-6, and FH9 breakers with live pots but are improvements on the latter. These breakers are for cell mounting and although they may be either bottom or back connected, in isolated phase arrangements they are usually back connected. When these breakers are used in a vertical isolated phase design it is necessary to have a paralleling mechanism mounted in the oil circuit breaker compartment over each pole. When this type of breaker is used in a horizontal vertical phase arrangement the paralleling mechanisms may be mounted on the mechanism floor directly above each pole. These breakers may be furnished with the plane of the pots perpendicular to the bus, so-called "parallel pots;" or parallel to the bus, so-called "tandem pots." Since the width of the oil circuit breaker cell is usually determined by that of the reactor cell, the length of the bus generally cannot be decreased by the use of parallel pots and they will cause an increase in the depth of cell which will increase the width of the building. The use of tandem pots greatly simplifies the connections between the oil circuit breakers and their disconnecting switches.

The Type FHD oil circuit breakers like the Type FH breakers open the circuit by an upward movement. The outside pots, however, unlike the Type FH, are dead; the arc being broken in an internal explosion chamber which is insulated from the outer pot. The contacts on top of the breaker are alive when the disconnecting switches are closed. These breakers may be mounted fixed in the cell or they may be mounted so that they will be easily removable from the cell in one of two ways. They may have the pots mounted upon a truck, which runs on rails set into the floor of the cell, or have wheels under the top of the switch which run on rails held by brackets mounted on the barrier walls. In either case bolted connections may be made to the oil circuit breakers or they may connect through truck type contacts mounted on the rear wall of the switch compartment. These breakers can be furnished with either "parallel" or "tandem" pots. The pots being dead it is possible to mount the paralleling mechanisms between them, these paralleling mechanisms being mounted on the same member that supports the pots. That is, if the pots are mounted upon a truck, the paralleling mechanism is mounted on the truck; if supported by the top of the switch, the paralleling mechanisms are underhung from the top of the switch.

The Type FHK-130 oil circuit breakers have a downward break. Each phase has two explosion chambers contained in, but insulated from, a round steel tank. The paralleling mechanism is located within the cover of the tank and each pole is operated by means of a shaft which comes out of a bearing in the side of the housing. These breakers can be mounted fixed in the cell, or upon a truck which runs on rails set into the floor, or on wheels under the top of the breaker which run on tracks supported by brackets on the barrier walls.

The operating rods of the FHD or FHK 130 oil circuit breakers are placed in the mechanism aisle with suitable bell cranks and levers to connect with the paralleling mechanisms. The operating mechanisms are mounted on the mechanism room floor directly above the aisle. These operating mechanisms are the same standard types that would be used in a conventional three-phase arrangement; motor operated mechanisms for the Type FH and FDH breakers and solenoid operated for the FHK-130 type breakers.

Horizontal separation may take, for the same type of oil circuit breaker, a larger mechanism than would be required for vertical separation.

In choosing between these types of oil circuit breakers the first consideration is interrupting capacity, the second is the available space. As stated before, the width of cell is usually dependent upon the width of the reactor cell which leaves only height and depth of cell to be considered. In the following table the approximate inside cell dimension of the various oil circuit breakers are given. These values are for "Tandem" arrangement and take into consideration not only the oil circuit breakers themselves but also the spacing of disconnecting switches, etc., and are given as tentative values only.

Type	Height	Width	Depth
FH-103 and 203	5 ft. 6 in.	3 ft. 0 in.	2 ft. 3 in.
FH-206	6 ft. 0 in.	3 ft. 6 in.	2 ft. 6 in.
FH-209	6 ft. 10 in.	4 ft. 2½ in.	2 ft. 6 in.
FHD-17	6 ft. 6 in.	4 ft. 0 in.	3 ft. 0 in.
FHD-21	7 ft. 6 in.	4 ft. 8 in.	3 ft. 6 in.

Potential Transformers

In the first part of this article we pointed out that electrical isolation was obtained by connecting all circuits to the bus through reactors. The potential transformers are an exception to this; but in order to maintain electrical isolation, they must be connected from bus to ground instead of from bus to bus.

This Y connection of potential transformers brings up the question of what connections should be used for metering. This depends upon the possibility of the equivalent of a fourth wire current through grounding at different points. There are two conditions which must be considered:

1st. If there is only one ground on the system and proper provision is made to immediately remove all other grounds as they appear. Under this condition three transformers may be used with both their primary and secondary windings connected in Y. This provides the equivalent of delta voltage transformation and a two-coil meter can be used. If assurance can be given against the continuance of external grounds this is the better of the two systems.

2nd. If the system is grounded in more than one place there are two connections which may be used depending upon whether one of the grounds is available or not. If it is, two potential transformers connected from bus to ground may be used. If not, three potential transformers connected from the three buses to a common point, with their impedances correctly adjusted to make this point a correct neutral for the system, may be used. In these latter cases a four-wire 3-phase (that is 3-coil) meter should be used.

The potential transformers should be connected to the bus through resistances and fuses as usual. It may be noted that in all of the arrangements shown potential transformers may be conveniently located between the reactor and the oil circuit breakers.

Current Transformers

Although by the use of an isolated phase design the currents which flow when short circuits occur are limited by the reactors to a value much less than that which might be obtained with a bus short circuit on a conventional three-phase layout, still, with the size of station which we are considering, these short circuit currents are of considerable magnitude, and the current transformers which must carry them should be of rugged construction. Probably the most rugged and easily installed type of current transformer is the bar type or slip over type either of which consists of a straight primary conductor about which a core carrying the secondary windings is placed. Such a current transformer can be designed with meter accuracy for high ratios but on the lower ratios the accuracy becomes poorer. Current transformers with multiple turn primaries which have meter accuracy on the lower ratios can be made with high mechanical strength but are more expensive and take up more space.

On the "FHK" type of oil circuit breakers it is possible to use bushing type current transformers. These, like the bar type current transformers, can be designed with meter accuracy for the higher ratios but on the lower ratios they are not as accurate as the bar type current transformers.

In a majority of the present existing and proposed isolated phase installations bar type current transformers have been used. If one refers to the arrangements of isolated phase stations shown in Figs. 1, 2, 4, 6, and 9 the convenience with which the current transformers can be installed in the connections between the reactors and the oil circuit breakers is apparent.

Current Limiting Reactors

Since current limiting reactors are one of the fundamental requisites of isolated phase construction, considerable attention should be given to their design and installation. The reactors should have the following characteristics:

- High mechanical strength
- Non-inflammability
- Low loss
- Ample electrical clearance between turns; between layers; and from windings to ground.

There seems to be a growing tendency among central station engineers to request that reactors be furnished with a larger cross section of conductor than has been used in the past. This is probably due partly to the fact that the load factors have increased to such a point that in capitalizing losses a greater initial investment is warranted in order to keep them to a low value; and also due to a desire to increase the thermal capacity of the reactor for short circuit conditions. In the past all of our feeder reactors have been designed to withstand for two seconds the current which would be obtained if sustained rated voltage was impressed across their terminals. We believe, however, that the cross section of the conductor used in a reactor should be such that it will carry abnormal current without failure for a greater length of time than the conductor which is connected to it.

In laying out the section of the building in which the reactors are to be placed care should be taken to make certain that it shall be possible to maintain certain definite magnetic clearances between the reactors and any iron work having a cross section greater than can be enclosed in a circle 1½ inches in diameter. An exception can be made of magnetic material having a cross section of ¼ inch or less by 12 inches or less.

In a large number of cases the width of the reactor cell (which is dependent upon the diameter of the reactor) is the factor which determines the length of the bus. It is desirable to keep the length of bus to as short a value as possible. There is usually plenty of head room, however, and therefore from the standpoint of building layout it is desirable to use a tall slender reactor. The most efficient design of reactor is ordinarily one in which the diameter is equal or greater than the height. The curves in Fig. 10 show for a typical rating of reactor the variations in height, cost, and watt loss plotted against diameter. These curves show that after a certain point is reached a decrease in diameter is obtained only by a considerable increase in the other factors. It will be noticed that the ordinate values of the second and third points are nearly equal. This is due to the necessity of using certain standard forms to conform with manufacturing conditions.

In certain cases it is preferable to limit the length of the station by adding slightly to the width. When this is the case it is possible to build the reactors with the planes of the coils vertical instead of horizontal; the latter being the usual construction for "cast in concrete" type of reactors. Under this condition an increase in the diameter of the reactor causes an increase in the height and depth necessary for the reactor cell. Within certain limits, then, the width of the cell may be decreased with an increase of the diameter of the reactor. For example, if such a reactor should be cast with the coils having the same size, number, and spacing as those of the reactor with the larger diameter in the above curves, it would have the following dimensions:

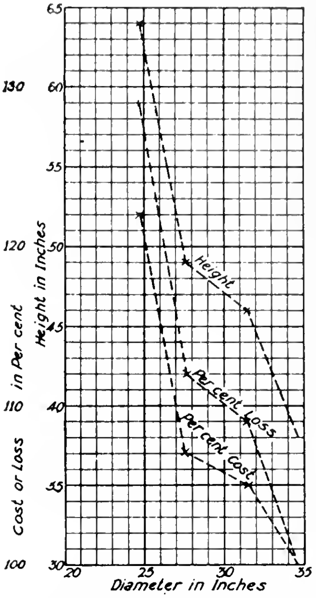

Fig. 10. Example of Variation in Height, Watt Loss, and Cost with Change of the Diameter of a Current Limiting Reactor

Height	Width	Depth
47 inch	25½ inch	34⅝-inch

The losses of course would be the same as those shown on the curve for the 34⅝ inch diameter reactor and the cost would be increased by about 5 per cent.

By balancing the saving in building cost due to the decreased length against the increased cost due to the decrease of diameter of the reactor, or in another case balancing the difference in cost due to the different shape of building against the change in cost due to a different shape of reactor, an economic balance may be obtained. There is of course no use in decreasing the size of the reactor cell to a value smaller than the necessary width of the oil circuit breaker cell.

All of the dimensions given have been those of the reactors themselves. In installing reactors in cells it is of course necessary to provide proper electrical and magnetic clearance, and unless the reactors are far enough apart (which is not generally the case) braces must be installed, which may further increase the clearance between the reactor and the cell walls.

In isolated phase installations the reactors in the various phases of the same circuit are installed with such a large distance between them that it is not necessary to brace them against the stresses due to a short circuit on any one feeder. If, however, a short circuit involves the same phase of two adjacent feeders at the same time, it is necessary in most cases to brace the reactors. Under such a condition the currents in similar phases of the two adjacent circuits will be in the same direction and the force between the leads connecting to the reactors will be attractive. The reverse is true of the reactors themselves if they are built and connected symmetrically. In this case there will be a repulsive force between the reactors. If all the reactors of one phase are installed in a single straight line, they may be braced against movement along that line by compression type braces. When the reactors of one phase are installed in two adjacent straight lines, there may be a repulsive force between corresponding reactors in the two lines, which cannot be checked by a compression type brace. In the latter case strain insulator braces may be used instead of the compression braces. These strain braces should be placed not only between adjacent reactors in the same line but also between the reactors in the two lines.

The leads coming and going to and from the reactors are usually installed with such distance between them that it is not necessary to brace heavily, against magnetic forces incident to short circuit; except that great care should be exercised in bracing such leads if they cut the field of the reactor transversely.

Ground and Test Buses

The location of ground and test buses will depend somewhat upon the arrangement of equipment and largely upon local conditions. It will be found, however, that these may be incorporated in the isolated phase design much more easily than in a conventional three-phase design.

Costs

There seems to be prevalent an opinion that isolated switch house construction requires large buildings, special equipment and in general is very expensive. The designs shown in the fore part of this article indicate that the isolated phase arrangements as there applied should not take up any more space and will probably effect a saving in size of building required for a conventional three-phase arrangement. A large number of comparative studies have been made which show in all instances a saving in cost of building in favor of isolated phase. The amount depends entirely on the type of equipment and arrangement used; in one of the above cases amounting to 15 per cent.

The cost of materials and labor used in the buses and connections show a considerable reduction for isolated phase, this again depending on the system of connections.

The cost of remote mechanically operated disconnecting switches will be increased 10 to 15 per cent, which is warranted by the improved operating conditions.

To change the mechanism of oil circuit breakers in order to make them suitable for isolated phase arrangement will increase their cost from 5 to 25 per cent, depending upon the type of oil circuit breaker used.

The cost of the reactors will be the same unless a special design of reactor has been used to effect a saving in building cost (see curve shown in Fig. 10).

The unit cost of instrument transformers will be approximately the same with a possible advantage for the isolated phase.

A considerable saving can also be made in the conduit system for instrument and control leads. This saving is not only in the first cost but also in maintenance.

The overall cost of an isolated phase switch house may or may not show a saving over the conventional arrangement, depending on the proportional effect of the factors listed above.

Conclusion

In the foregoing paragraphs it has been shown that isolated phase arrangements possess many desirable features, which would justify an increase in cost. These features, however desirable, are nevertheless incident to the design. The basic idea of isolated phase arrangement is to eliminate all bus short circuits from phase to phase. (It is understood that short circuits from one phase of bus to ground will be limited by the use of a neutral grounded resistor.)

The elimination of phase to phase short circuits is obtained by spacing the buses a considerable distance apart with fire walls between them. All circuits are connected to these buses through reactors which are spaced apart in the same manner as the bus. After a circuit is passed through these reactors it is no longer part of the bus. The only way in which a bus short circuit from phase to phase can occur is as a simultaneous failure of two reactors on the same circuit or as simultaneous faults to ground in two phases. With properly designed reactors the former case is very improbable. Also if the buses are properly insulated and installed, simultaneous failures of two phases to ground are quite improbable. It is admitted that with a well designed conventional three-phase bus properly installed, a phase to phase bus short circuit is an infrequent occurrence; but there is a possibility of its taking place with consequent damage to property, service and possibly life. It is the duty of every engineer responsible for the design and construction of a large power station to investigate such possibilities and eliminate them wherever feasible. In the case of the elimination of bus short circuits we believe that the answer is "ISOLATED PHASE."

A Transmission Line Calculator

By Edith Clarke

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The author shows that the equations met in transmission line problems are capable of solution on a calculator. She has designed such a calculator and describes it and its use in the present article. Two supplements, included in the article, furnish a calculator in paper form together with directions for its assembly and use.—Editor.

Transmission line calculations, as ordinarily performed by means of the well-known series or hyperbolic formulas, require a great deal of time and labor. In order to reduce the time and labor involved, a transmission line calculator has been developed, a working model of which is given in Supplements I and II. This Calculator may be assembled according to the directions for assembling given on Supplement II and operated according to the directions for use given on Supplement I.

The Transmission Line Calculator is a mechanical device which solves graphically equations which consider the effect of distributed resistance, inductance and capacitance. The effect of leakance is neglected in this Calculator, although it is possible to design a calculator which will include it. Certain assumptions have been made in designing the Calculator for which corrections may be applied where a high degree of precision is desired. Any degree of precision may be obtained with this type of calculator if sufficiently large and free from mechanical defects. The working model of the Calculator given in Supplements I and II, if carefully assembled, may be used to advantage for preliminary calculations in connection with proposed transmission lines. If mechanically correct, it will give results without appreciable error for lines up to 250 miles in length at 60 cycles, 300 miles at 50 cycles, or 600 miles at 25 cycles. For lines 400 miles in length at 60 cycles the error may be about 1 per cent. The error increases with the length of line, but even at the extreme range of the Calculator it will not be more than about 2 per cent for voltage and current values. Since the power at the generator end is obtained from the product of voltage and current, the error in the power may be twice as large as that in voltage or current. It is possible by applying corrections to the calculator given in Supplement I to eliminate all errors, but this is hardly worth while on a paper calculator, mechanically defective. Transmission lines may easily be calculated on the Calculator in less than one-tenth the time ordinarily required for similar calculations made in the customary manner.

To test an assumed transmission line for satisfactory operation, it is customary to start at the receiver end, assuming all conditions as desired at that end, then to calculate by means of suitable equations the conditions at the generator end. The procedure with the Calculator is the same, the only difference being that the Calculator solves the equations graphically by means of movable vectors. In this discussion, the transformers at the ends of the line are not included. Generator end and receiver end refer to the ends of the line on the high-voltage sides of the transformers.

THEORY OF CALCULATOR

The equations upon which the Calculator is based are as follows:*

$$e_g = e_r\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+\ldots\right) + I_rZ\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5040}+\ldots\right) \quad (1)$$

$$I_g = I_r\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+\ldots\right) + e_rY\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5040}+\ldots\right) \quad (2)$$

The following notation will be used throughout:

E_g = Volts between lines at generator end
E_r = Volts between lines at receiver end
KV_g = Kilovolts between lines at generator end
KV_r = Kilovolts between lines at receiver end
$e_g = E_g/\sqrt{3}$ = volts to neutral at generator end
$e_r = E_r/\sqrt{3}$ = volts to neutral at receiver end
I_g = Amperes line at generator end
I_r = Amperes line at receiver end
KW_r = Total kilowatts at receiver end
$KV\text{-}A_c$ = Total kv-a. of condenser at receiver end
l = Length of line in miles
f = Frequency in cycles per second
R = Resistance per mile of one conductor in ohms
L = Inductance per mile of one conductor in henries
C = Capacitance per mile of one conductor in farads
$X = 2\pi fL$ = Reactance per mile of one conductor to neutral in ohms
$z = R + jX$ = Impedance per mile of one conductor to neutral in ohms
$Z = lz = l\,(R+jX)$ = Total impedance of one conductor to neutral in ohms
$y = 0 + j\ 2\pi fC$ = Admittance per mile of one conductor to neutral in mhos (Leakance = 0)
$Y = ly = l\,(j2\pi fC)$ = Total admittance of one conductor to neutral in mhos
$(p.f.)_g$ = power-factor at generator end
$(p.f.)_r$ = power-factor at receiver end
$K = KW_r/KV_r^2$ = Ratio of kilowatts at receiver end to square of kilovolts at receiver end
$K' = KV\text{-}A_c/KV_r^2$ = Ratio of condenser kilovolt-amperes to square of kilovolts at receiver end
S/D = Ratio of flat spacing between conductors in feet to diameter of conductor in inches

Any desired degree of accuracy may be obtained by using equations (1) and (2) for transmission line calculations, provided a sufficient number of terms of the series are taken. For lines under 200 miles in length with a frequency of 60 cycles per second, two terms of the series ordinarily give results sufficiently accurate, but for longer lines, or higher frequencies, more terms of the series should be used. The Calculator may be used with lines of any length, but when the lines are long and the calculations become laborious, the Calculator is most useful, for the third and higher terms of the series have been taken into consideration in the design of the Calculator whenever it was found necessary to do so.

Equations (1) and (2) may be further simplified and made more convenient for numerical calculations if equation (1) is divided by e_r, and equation (2) by I_r.

$$\frac{e_g}{e_r} = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right) + \frac{I_r}{e_r}Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

$$\frac{I_g}{I_r} = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right) + \frac{e_r}{I_r}Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

Since $I_r = \frac{KW_r}{\sqrt{3}\,KV_r\,(p.f.)_r}$ in magnitude and

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* See "Engineering Mathematics," page 206, by C. P. Steinmetz.

makes an angle ϕ with e_r such that $\cos\phi = (p.f.)_r$.

$$\frac{I_r}{e_r} = \frac{KW_r}{\sqrt{3}\,KV_r e_r\,(p.f.)_r}(\cos\phi \pm j\sin\phi)$$

If K replaces $\frac{KW_r}{KV_r^2}$,

$$\frac{I_r}{e_r} = \frac{K \cdot 10^{-3}}{(p.f.)_r}(\cos\phi \pm j\sin\phi)$$

the positive sign in the ± ambiguity to be used when the power-factor at the receiver end is leading, and the negative sign when it is lagging.

Equations (1) and (2) now become:

$$\frac{e_g}{e_r} = \frac{E_g}{E_r} = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)+ \frac{K10^{-3}Z}{(p.f.)_r}\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+.\right)(\cos\phi \pm j\sin\phi) \quad (3)$$

$$\frac{I_g}{I_r} = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)+ \frac{(p.f.)_r\,Y}{\mathrm{K}10^{-3}}\,\frac{\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)}{(\cos\phi \pm j\sin\phi)} \quad (4)$$

E_g/E_r is a vector quantity whose magnitude is the ratio of the voltage at the generator end to the voltage at the receiver end and whose slope is the angle by which the voltage at the generator end leads the voltage at the receiver end.

I_g/I_r is a vector quantity whose magnitude is the ratio of the current at the generator end to the current at the receiver end and whose slope is the angle by which the current at the generator end leads the current at the receiver end.

Assumptions

The Transmission Line Calculator solves the equations (3) and (4) graphically when the following assumptions are made:

1. The real part of the series
$$\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$
is a function of the product of frequency and length of line, and for a given value of this product is independent of the line constants.
2. The vector magnitude of the series
$$\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$
is a function of the product of frequency and length of line, and for a given value of this product is independent of the line constants.

When the product of frequency in cycles per second and length of line in miles is less than 15,000 (i.e., 250 miles at 60 cycles or 600 miles at 25 cycles, $fl = 15{,}000$), the error in the above assumptions is negligible. The error increases as the product, fl, increases, but it is less than 1 per cent throughout the range of this calculator.

The series involved in equations (3) and (4) are vector quantities, and may be denoted as follows:

$$\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right) = a = a_1 + ja_2$$

$$\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right) = b = b_1 + jb_2$$

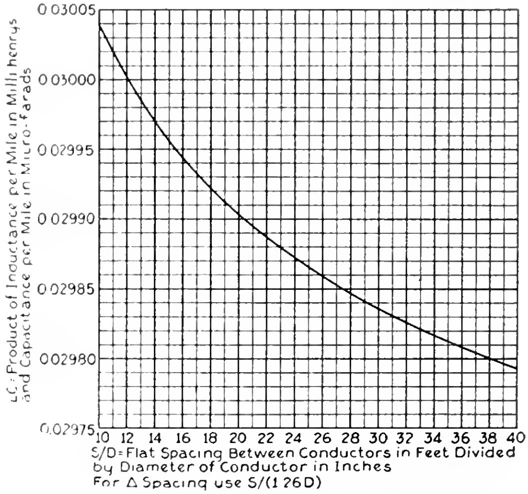

Fig. 1. Product of Inductance and Capacitance per Mile for Single Conductor

If substitution is made for Z and Y in the series in terms of R, L, C, f and l, it can be shown that the real parts of these vectors, a_1 and b_1, are approximately constant for a given product of frequency and length of line. This is due to the fact that the product of L and C is practically constant for high-voltage transmission lines. The product LC as a function of S/D, the ratio of the flat spacing between the conductors in feet to the diameter of the conductor in inches, is given in Fig. 1. The familiar formulas* for L and C are given in terms of the ratio of triangular spacing between conductors and radius of the conductor, expressed in the

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* $L = (0.7411 \log_{10} s/r + 0.08047)\ 10^{-3}$ henries.

$C = \frac{0.03883}{\log_{10} s/r} 10^{-6}$ farads. Where s is average spacing between conductors in inches, and r is radius of the conductor in inches.

same units. S/D, the ratio of the flat spacing between conductors in feet to the diameter of the conductor in inches, is used here because of its greater convenience. For high-voltage transmission lines, S/D lies between 10 and 40. The product LC is approximately constant within this range of S/D. If an average value of S/D is assumed, for example, $S/D=20$, and the corresponding value of LC selected, the error in assuming LC constant for all high-voltage transmission lines will be very small. Although a_1 and b_1 are not independent of the line constants, they are but little affected by variations in these constants, except for very long lines.

TABLE I

a_1 AND b_1 FOR VARIOUS LINE CONSTANTS WITH $fl=15{,}000$ AND 30,000

fl	f cycles	l miles	R ohms	S/D	a_1	b_1
15000	60	250	0.2	20	0.8699	0.9563
15000	60	250	0.2	10	0.8693	0.9562
15000	60	250	0.2	40	0.8704	0.9564
15000	60	250	0.1	20	0.8701	0.9563
15000	60	250	0.3	20	0.8697	0.9563
15000	50	300	0.2	20	0.8698	0.9563
30000	60	500	0.2	20	0.5116	0.8316
30000	60	500	0.2	10	0.5089	0.8306
30000	60	500	0.2	40	0.5137	0.8323
30000	60	500	0.1	20	0.5136	0.8320
30000	60	500	0.3	20	0.5084	0.8309
30000	50	600	0.2	20	0.5104	0.8313

If line constants are assumed and these series calculated for various values of fl (the product of frequency and length of line) it will be seen that for lines of such length that only two terms of the series need be used, the real parts, a_1 and b_1, of these series are independent of the line constants. That is, for a given product of frequency and length of line, a_1 and b_1 are constant no matter what the line constants. For long lines, where the third and even higher terms of the series need be used, a_1 and b_1 vary with variations in the line constants, but the variation is not great even for the extreme range of the Calculator. It is possible, therefore, to calculate a_1 and b_1 from average line constants for various values of fl and to assume, with but slight error, that these values of a_1 and b_1 are constant for a given value of fl.

Table I gives a_1 and b_1 for various line constants with $fl=15{,}000$ and 30,000.

Calculations of a and b for various lengths of line at 50 and 60 cycles with $R=0.2$ ohms per mile and $S/D=20.9$ are given in Table II. The vector magnitude and slope, as well as the real and imaginary parts of the series, are given. These values of a and b were used in making the Calculator.

Equations Solved Graphically by Calculator

The Transmission Line Calculator is designed to solve graphically equations (3) and (4). The right-hand members of these equations consist of two terms each, both of which are vectors. E_g/E_r and I_g/I_r are likewise vectors. In order that the magnitude and slope of E_g/E_r and I_g/I_r may be readily determined, the Calculator is provided with a polar coördinate chart. The magnitude of the vector E_g/E_r is the ratio of the voltage at the generator end to the voltage at the receiver end, and the magnitude of the vector I_g/I_r is the ratio of the current at the generator end to the current at the receiver end. Distances from the center of coördinates measured along the radii represent the magnitudes of the vectors E_g/E_r and I_g/I_r. The slope of the vector E_g/E_r is the angle by which E_g leads E_r. With E_r as standard phase, the angular displacement from the base line represents the slope of the vector E_g/E_r. The slope of the vector I_g/I_r is the angle by which I_g leads I_r. With I_r as standard phase, the angular displacement from the base line represents the slope of the vector I_g/I_r.

Voltage

E_g/E_r is the sum of the two vectors

$$\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$

and

$$\frac{K\,10^{-3}Z}{(p.f.)_r}\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+.\right)(\cos\phi \pm j\sin\phi).$$

The Calculator adds these two vectors.

For short lines when the first vector reduces to $\left(1+\frac{ZY}{2}\right)$ we must add vecto-

TABLE II

VALUES OF *a* AND *b* WHICH WERE USED FOR THE TRANSMISSION CALCULATOR

R = 0.2 ohms per mile and S/D = 20.9

Length of Line Miles	$a=(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+..)$	$b=(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5040}+..)$	Length of Line Miles	$a=(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+..)$	$b=(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5040}+..)$
60 Cycles					
50	$0.9947+j0.00131$ $0.9947\ \underline{/0°5'}$	$0.9982+j0.00044$ $0.9982\ \underline{/0°2'}$	400	$0.6779+j0.0745$ $0.6820\ \underline{/6°16'}$	$0.8903+j0.0260$ $0.8907\ \underline{/1°40'}$
100	$0.9788+j0.00519$ $0.9788\ \underline{/0°18'}$	$0.9929+j0.00174$ $0.9929\ \underline{/0°6'}$	450	$0.5981+j0.0914$ $0.6050\ \underline{/8°41'}$	$0.8624+j0.03226$ $0.8360\ \underline{/2°9'}$
150	$0.9526+j0.01157$ $0.9527\ \underline{/0°42'}$	$0.9841+j0.003882$ $0.9841\ \underline{/0°14'}$	500	$0.5118+j0.1088$ $0.5232\ \underline{/1°20'}$	$0.8318+j0.0389$ $0.8327\ \underline{/2°4'}$
200	$0.9162+j0\ 0203$ $0.9164\ \underline{/1°16'}$	$0.9719+j0.00685$ $0.9719\ \underline{/0°24'}$	550	$0.4197+j0.1264$ $0.4383\ \underline{/16°46'}$	$0.7984+j0.0462$ $0.7997\ \underline{/3°18'}$
250	$0.8700+j0.0312$ $0.8706\ \underline{/2°3'}$	$0.9563+j0.01060$ $0.9564\ \underline{/0°38'}$	600	$0.3228+j0.1438$ $0.3534\ \underline{/24°1'}$	$0.7629+j0.0536$ $0.7647\ \underline{/4°1'}$
300	$0.8145+j0.0441$ $0.8157\ \underline{/3°6'}$	$0.9374+j0\ 01508$ $0.9375\ \underline{/0°55'}$	650	$0.2220+j0.1606$ $0.2740\ \underline{/35°53'}$	$0.7252+j0.0612$ $0.7278\ \underline{/4°50'}$
350	$0.7502+j0.0586$ $0.7525\ \underline{/4°28'}$	$0.9154+j0.02024$ $0.9156\ \underline{/1°16'}$			
50 Cycles					
50	$0.9963+j0.00109$ $0.9963\ \underline{/0°4'}$	$0.9988+j0.000363$ $0.9988\ \underline{/0°2'}$	450	$0.7146+j0.0799$ $0.7191\ \underline{/6°23'}$	$0.9031+j0.0277$ $0.9035\ \underline{/1°45'}$
100	$0.9853+j0.00434$ $0.9853\ \underline{/0°15'}$	$0.9951+j0.00145$ $0.9951\ \underline{/0°5'}$	500	$0.6514+j0.09625$ $0.6585\ \underline{/8°24'}$	$0.8812+j0.03368$ $0.8818\ \underline{/2°11'}$
150	$0.9670+j0.00970$ $0.9670\ \underline{/0°34'}$	$0.9890+j0.00325$ $0.9890\ \underline{/0°11'}$	550	$0.5832+j0.1134$ $0.5941\ \underline{/11°0'}$	$0.8571+j0.04021$ $0.8580\ \underline{/2°41'}$
200	$0.9415+j0.01710$ $0.9417\ \underline{/1°2'}$	$0.9804+j0.00574$ $0.9804\ \underline{/0°20'}$	600	$0.5104+j0.1311$ $0.5270\ \underline{/14°24'}$	$0.8313+j0.04706$ $0.8326\ \underline{/3°14'}$
250	$0.9091+j0.0264$ $0.9095\ \underline{/1°40'}$	$0.9695+j0.00891$ $0.9695\ \underline{/0°32'}$	650	$0.4336+j0.1489$ $0.4584\ \underline{/18°57'}$	$0.8037+j0.0542$ $0.8055\ \underline{/3°48'}$
300	$0.8699+j0.0375$ $0.8707\ \underline{/2°28'}$	$0.9563+j0.01273$ $0.9564\ \underline{/0°46'}$	700	$0.3532+j0.1666$ $0.3905\ \underline{/25°15'}$	$0.7744+j0.0616$ $0.7768\ \underline{/4°33'}$
350	$0.8242+j0.0503$ $0.8257\ \underline{/3°29'}$	$0.9408+j0.01716$ $0.9410\ \underline{/1°3'}$	750	$0.2698+j0.1840$ $0.3266\ \underline{/34°18'}$	$0.7436+j0.0692$ $0.7468\ \underline{/5°19'}$
400	$0.7723+j0.0645$ $0.7750\ \underline{/4°46'}$	$0.9230+j0.02216$ $0.9233\ \underline{/1°23'}$			

rially 1 and $\frac{ZY}{2}$. On the polar coördinate chart, we locate 1; it is at the point *P*. In order to add $\frac{ZY}{2}$ to 1, we must apply at the point *P* a vector which has the same slope as $\frac{ZY}{2}$. The slope of *Z* is determined by the ratio of the reactance, *X*, to the resistance, *R;* the slope of *Y* is 90 deg. when the leakance is neglected. The slope of *ZY* is therefore the slope of $Z+90$ deg.* In order to represent graphically $\frac{ZY}{2}$ with its proper slope, a movable vector, Vector No. 1 of the Calculator, is pivoted at point *P* and set with a slope of $Z+90$ deg. This is accomplished by considering *P* the origin of rectangular coördinates. If the abscissas to the left of *P* correspond to $-X$, and the ordinates to *R*, and the center line of Vector No. 1 is set over the point $(-X, R)$, Vector No. 1 will be perpendicular to *Z*. The distance from *P* to the point $(-X, R)$ will be $\sqrt{R^2+X^2}=z$. If Vector No. 1 is graduated to the same scale as *X* and *R*, the magnitude of *z* can be read directly on Vector No. 1 over the point $(-X, R)$. The same scale must be chosen for *R*, *X* and *z*, but this scale need not be the same as the other scales of the calculator. To the left of the polar coördinate chart on Supplement I is another chart which is provided with equally spaced horizontal lines corresponding to various values of "$R=$ Resistance per mile in ohms" and unequally spaced vertical lines corresponding to various values of *S/D*, one set for 50 cycles and one for 60 cycles. Since *X* is uniquely determined for a given value of *S/D* and a given frequency, these vertical lines have been graduated in terms of *S/D* rather than *X*. Since *X* is not needed directly, it is not given in the Calculator. *X* and *Y* as functions of *S/D* are given in Figs. 2 and 3. Knowing *S/D* and *R* for a given line, a point is located on the *S/D*, *R* Chart whose horizontal distance from *P* is *X* and whose vertical distance above the zero axis is *R*. Vector No. 1 is swung about *P* until its "*z* Scale" is over this point. The slope of Vector No. 1 is the slope of $Z+90$ deg. and Vector No. 1 is parallel to *ZY*. On Fig. 4 *OS* is the vector representing the series

$$\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$

OT represents the real part, a_1, and *TS* the imaginary part, a_2. It has been pointed out that a_1 is practically constant for a given frequency and length of line; the distance *OT*, for a given frequency and length of line, is therefore known. Vertical lines marked "Length of Line—Miles" have been drawn

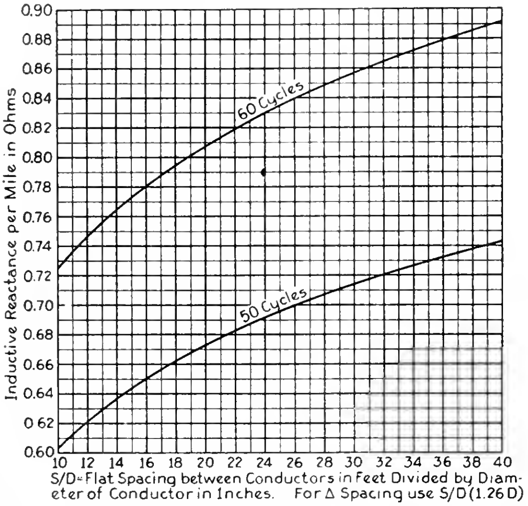

Fig. 2. Inductive Reactance per Mile for Single Conductor for 50 and 60 Cycles

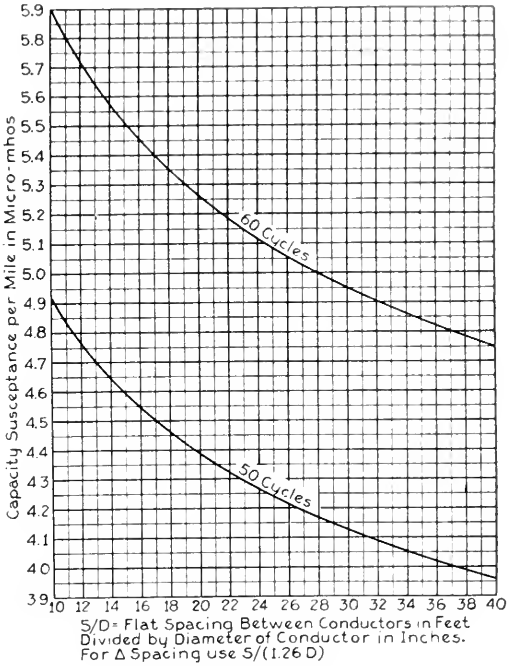

Fig. 3. Capacity Susceptance per Mile to Neutral for 50 and 60 Cycles

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*For a concise treatment of the multiplication of plane vectors see "Artificial Electric Lines," page 117, by A. E. Kennelly.

on the Calculator to represent a_1 for various lengths of line at frequencies of 50 and 60 cycles. The intersection of Vector No. 1 with one of these vertical lines, or lines produced, will locate S corresponding to any desired frequency and length of line. There is no error in this method of locating S when the lines are of such length that two terms only of the series need be used, but as the length of the line increases, the error in this method of locating S increases. For long lines it is found that although OT represents a_1 to a high degree of accuracy, TS is greater than a_2. This error in a_2 may be calculated from a series, the first term of which is $R\frac{Xy^2}{24}l^4$, and applied as a correction to E_g/E_r and I_g/I_r in the form of a vector, of length equal to the error, extending vertically downward. The error in the calculated E_g/E_r and I_g/I_r caused by this method of representing the series

$$\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$

will be negligible for a 250-mile line at 60 cycles, or a 600-mile line at 25 cycles; it will be less than 1 per cent for lines of 400 miles or less in length and a frequency of 60 cycles. For the extreme range of the Calculator, the error may be in the neighborhood of 2 per cent. It is probably not worth while to correct for this error when using the paper calculator given in Supplement I, but it may be worth while to remember that the error tends to make the calculated values too high, rather than too low.

After the end point, S, of the vector representing the series

$$\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$

is located, the second term of the right-hand member of equation (3) is added vectorially. Vector No. 2 must represent this second term in magnitude and slope. Vector No. 2, therefore, must slide along Vector No. 1 until its pivot is over the intersection of Vector No. 1 with the vertical line, or line produced, of the "Length of Line—Miles" scale corresponding to the given frequency and length of line. The magnitude of this term may be expressed very simply as

$$\frac{KQz}{(p.f.)_r}$$

if Z is replaced by its equal, zl, and

$$10^{-3}l\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}\cdot\cdot\cdot\right)$$

is replaced by Q in magnitude and θ in slope. From an inspection of Table II which gives

$$\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}\ \ldots\right)$$

for various lengths of line at frequencies of 50 and 60 cycles for average line constants, it is apparent that the magnitude of this vector is but little greater than its real part, and, since the real part is constant for a given frequency and length of line, the magnitude of the vector is determined when the frequency and length of line are known. The "Q Table" of the Calculator gives the magnitude of this series multiplied by $10^{-3}l$ for various lengths of line at 50 and 60 cycles. The error in assuming Q constant for a given frequency and length of line is negligible throughout the range of the Calculator. The slope, θ, of the series varies directly with R; it varies also with C, as may be seen if the series is expanded in terms of the line constants, but since the angle in all cases is small, the error in assuming that θ varies directly as R, but is independent of the other line constants, is not serious. The "θ Table" on the Calculator gives this angle for various lengths of line for 50 and 60 cycles with $R=1$ ohm per mile. When only approximate results are desired, θ may be disregarded entirely. When great precision is desired, the angles in the "θ Table" should be corrected for variations in capacitance, as well as for variations in resistance.

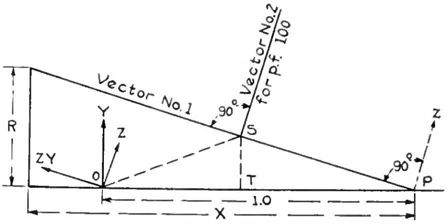

Fig. 4. Vector Representation of the Transmission Line Calculator

At unity power-factor, the factor ($\cos\phi \pm j\sin\phi$) is equal to one, and if θ, the slope of the vector representing the series

$$\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

is disregarded for the present, but applied as a correction to the slope of Vector No. 2 later, the second term of the right-hand member of equation (3) may be represented by a vector whose magnitude is KQz and whose slope is the slope of Z. If Vector No. 2 is placed perpendicular to Vector No. 1 it will have the same slope as Z, since Vector No. 1 is perpendicular to Z. For any power-factor other than unity, Vector No. 2 must be turned from its unity power-factor position, through an angle ϕ, such that $\cos \phi = (p.f.)_r$. The circular head of Vector No. 2 is graduated in terms of power-factor, so that Vector No. 2 may be given the slope corresponding to any given power-factor at the receiver end. After Vector No. 2 has been given the slope corresponding to the given power-factor, the slope of the series

$$\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

should be taken into consideration if the line is long enough to necessitate doing so. This is done by turning Vector No. 2 through an angle θ corresponding to the slope of the series. The magnitude of the vector measured along Vector No. 2 will be

$$\frac{KQz}{(p.f.)_r}.$$

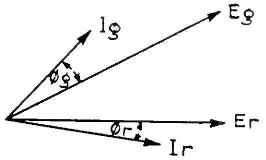

Fig. 5. Example of Vector Quantities used in Determining Generator Power-factor

Where $K = KW/KV_r^2$, Q, corresponding to the given frequency and length of line, is taken from the "Q Table" and z, the impedance per mile in ohms, is read on Vector No. 1.

$$\frac{KQz}{(p.f.)_r}$$

is calculated on the slide rule and this quantity laid off along Vector No. 2 by means of the scale on Vector No. 2. Directly under the point

$$\frac{KQz}{(p.f.)_r}$$

of Vector No. 2, $E_g\ E_r$ is located and its magnitude and slope read by means of the polar coördinates.

Current

Equation (4) may be treated in the same way as equation (3). The first term of the right-hand member is the same as in equation (3). For unity power-factor, the second term will have the slope of Y, if the small angle of the series

$$\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

is neglected for the present and applied as a correction later. When Vector No. 2 represents this second term for unity power-factor, it must have the slope of Y, but Y is a pure imaginary with a slope of 90 deg., therefore, to give Vector No. 2 the proper slope, it must make an angle of 90 deg. with the base line. Disc No. 3 is pivoted about the same center as Vector No. 2 and is graduated in terms of power-factor at the receiver; it should be set with its unity power-factor line in a vertical position. Disc No. 3 is held in this position and Vector No. 2 is rotated under it and given a slope corresponding to the power-factor at the receiver end by making Vector No. 2 coincident with the proper power-factor line of Disc No. 3. The slope of Vector No. 2 may now be corrected for the small angle θ of the series

$$\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

If Y is replaced by its equal, yl, and

$$10^{-3}l\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

by Q, the magnitude of the second member of the right-hand side of equation (4) will be

$$\frac{yQ\ (p.f.)_r}{K}$$

where y, the capacity susceptance per mile in micro-mhos, is taken from the "y curves," Q, corresponding to the given frequency and length of line, is taken from the "Q Table," and $K = KW/KV_r^2$.

$$\frac{yQ\ (p.f.)_r}{K}$$

is calculated on the slide rule and its value laid off along Vector No. 2 by means of the scale on Vector No. 2. Directly under the point

$$\frac{yQ\ (p.f.)_r}{K}$$

of Vector No. 2, $I_g\ I_r$ is located and its magnitude and slope read by means of the polar coordinates.

Power-factor

The power-factor at the generator end of the line is calculated from the phase differences between E_g and E_r, between I_g and I_r and between I_r and E_r. With E_r

as standard phase, an inspection of Fig. 5 shows:

$$(p.f.)_g = \text{Cos}\ \phi_g$$
$$= \text{Cos}\ (\text{angle}\ I_r/I_g - \text{angle}\ E_g/E_r \pm \phi_r).$$

ϕ is positive when $(p.f.)_r$ is leading, and negative when it is lagging. If the angle in the parenthesis comes out positive, the generator power-factor is leading; if negative, it is lagging.

Power

The power at the generator end of the line is calculated from the following equation:

$$KW_g/KW_r = (E_g/E_r)(I_g/I_r)(p.f.)_g/(p.f.)_r.$$

Since the conditions at the receiver end are known, E_g, I_g and KW_g are easily calculated from E_g/E_r, I_g/I_r and KW_g/KW_r.

No Load

With no load at the receiver end, $K=0$ and equation (3) becomes:

$$E_g/E_r = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right) \qquad (5)$$

The end point of the vector representing the series

$$\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$

is located as above in finding E_g/E_r and I_g/I_r with a load on the line. The end point of the vector is at the pivot of Vector No. 2. E_g/E_r may be read by means of the polar coördinates on the Base Chart directly under this pivot when Vectors No. 1 and No. 2 are made of some transparent material; but when they are opaque, like the ones given in this article, Vector No. 1 should be replaced by a straight edge and E_g/E_r read, on the Base Chart, at its intersection with the vertical line, or line produced, of the "Length of Line—Miles" scale corresponding to the given frequency and length of line.

Condenser at Receiver End

When a synchronous condenser is used at the receiver end to furnish a lagging current at no load, and thus to prevent the receiver voltage from rising too high,

$$I_r = -j\frac{KV\text{-}A_c}{\sqrt{3}KV_r}$$

$$\frac{I_r}{e_r} = -j\frac{KV\text{-}A_c}{KV_r^2}10^{-3} = -j\,K'\,10^{-3}$$

where $KV\text{-}A_c$ = total kv-a. of the condenser and

$$K' = \frac{KV\text{-}A_c}{KV_r^2}$$

Equation (3) now becomes:

$$E_g/E_r = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$
$$-jK'\,10^{-3}Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right) \qquad (6)$$

When equation (6) is compared with equation (3) it is seen that the second term in the right-hand member of equation (6) has a slope which is 90 deg. less than the slope of the corresponding term in equation (3) when the power-factor at the receiver end is unity. To represent this second term of equation (6) Vector No. 2 must be turned through an angle of 90 deg. in a negative direction from its position at unity power-factor. Vector No. 2 will then make an angle of 180 deg. with Vector No. 1. The magnitude of this term is $K'Qz$ when Z is replaced by zl and

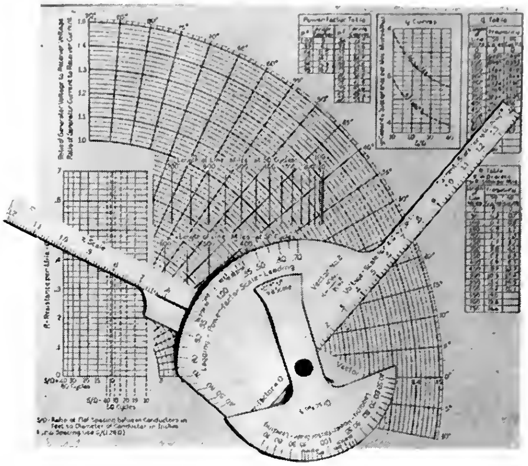

Fig. 6. Transmission Line Calculator Assembled

$$10^{-3}l\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

by Q. It may be calculated on the slide rule and this quantity laid off along Vector No. 2. Directly under the point $K'Qz$ of Vector No. 2, E_g/E_r is located and its magnitude and slope read by means of the polar coördinates.

Charging Current

The charging current at no load is obtained from equation (2) by substituting zero for I_r.

$$I_g = e_r\,Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

If Y is replaced by yl and

$$10^{-3}\,l\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

A Transmission Line Calculator

Patent Applied For

By Edith Clarke

DIRECTIONS FOR USE

I. For 50 and 60 cycles.

Divide flat spacing between conductors in feet by diameter of conductor in inches, obtaining S/D. For △ spacing use $S/(1.26D)$. Vector No. 1 pivots about point P. Bring it to rest so that "z Scale" is over the intersection of R, located on "R = Resistance per mile-ohms" scale, and S/D at the given frequency. Read z. Slide Vector No. 2 along Vector No. 1 until its pivot is over the intersection of Vector No. 1 with the vertical line (or line produced) of the "Length of Line—Miles" scale corresponding to the given frequency and length of line. Vector No. 1 and pivot of Vector No. 2 remain in these positions throughout the calculations.

A. Voltage. E_g/E_r = Ratio of voltage at generator end to voltage at receiver end.

1. With Load. Swing Vector No. 2 about its pivot until the given power-factor is coincident with the center line of Vector No. 1. Correct slope of Vector No. 2 by placing zero of "$R\theta$ Scale" of Disc No. 3 coincident with Vector No. 2, then holding Disc No. 3 fixed, turn Vector No. 2 under it counter-clockwise through an angle $R\theta$, where R = resistance per mile in ohms and θ corresponding to the given frequency and length of line, is taken from the "θ Table." With a slide rule obtain $zQK/(p.f.)_r$. z is read on "z Scale" of Vector No. 1. Q at given frequency and length of line is taken from the "Q Table." $(p.f.)_r$ = power-factor at receiver end. $K = KW_r/KV_r^2$. KW_r = total kw. at receiver end. KV_r = kv. between lines at receiver end. By means of the polar coördinates of the Base Chart, read the magnitude and angle of E_g/E_r directly under the point on Vector No. 2, whose distance from the pivot is $zQK/(p.f.)_r$.

2. No Load—No Condenser. Read E_g/E_r on the Base Chart directly under the pivot of Vector No. 2.

3. No Load—Condenser Taking Lagging Current. Turn Vector No. 2 about its pivot until zero power-factor line is coincident with Vector No. 1 (Vector No. 2 extending towards the right). With a slide rule, obtain zQK'. Where $K' = KV\text{-}A_c/KV_r^2$, $KV\text{-}A_c$ = total kv-a. of Condenser. Read E_g/E_r on the Base Chart directly under the point on Vector No. 2 whose distances from the pivot is zQK'.

B. Current. I_g/I_r = Ratio of current at generator end to current at receiver end.

1. With Load. Place Disc No. 3 with the "Power-factor Scale" upward and unity power-factor line vertical. Swing Vector No. 2 about its pivot until it coincides with the given power-factor on Disc No. 3. Correct slope of Vector No. 2 by angle $R\theta$ as above. With a slide rule, obtain $yQ(p.f.)_r/K$. y corresponding to the calculated S/D and the given frequency is obtained from the "y curves." Q, $(p.f.)_r$ and K as above. By means of the polar coördinates of the Base Chart, read the magnitude and angle of I_g/I_r directly under the point on Vector No. 2, whose distance from the pivot is $yQ(p.f.)_r/K$.

2. No Load—Charging Current.

$$I_g = \frac{KV_r}{\sqrt{3}} yQ.$$

Where KV_r = kv. between lines at the receiver end. y and Q as above.

3. Short Circuit Currents.

$$I_r = \frac{KV_g}{\sqrt{3}Qz.}$$

$$I_g = \frac{KV_g}{\sqrt{3}Qz.} \quad (E_g/E_r \text{ at no load})$$

KV_g = kv. between lines at the generator end, Q, z and (E_g/E_r at no load) as above.

C. Generator power-factor $= (p.f.)_g$.

With E_r as standard phase, an inspection of Fig. 5* shows:

$(p.f.)_g = \cos \phi_g = \cos$ (angle I_g/I_r—angle $E_g/E_r \pm \phi_r$)

ϕ_r is positive when $(p.f.)_r$ is leading and negative when lagging. If the angle in the parenthesis comes out positive, the generator power-factor is leading; if negative, it is lagging.

D. Power. KW_g/KW_r = Ratio of power at generator end to power at receiver end.

$KW_g/KW_r = (E_g/E_r)\ (I_g/I_r)\ (p.f.)_g/(p.f.)_r$.

II. For any frequency:

For any frequencies, f, other than 50 or 60 cycles, find a new Resistance $R' = R\frac{50}{f}$ and a new length of line, $l' = l\frac{f}{50}$; then with these new values proceed as above for a 50-cycle line.

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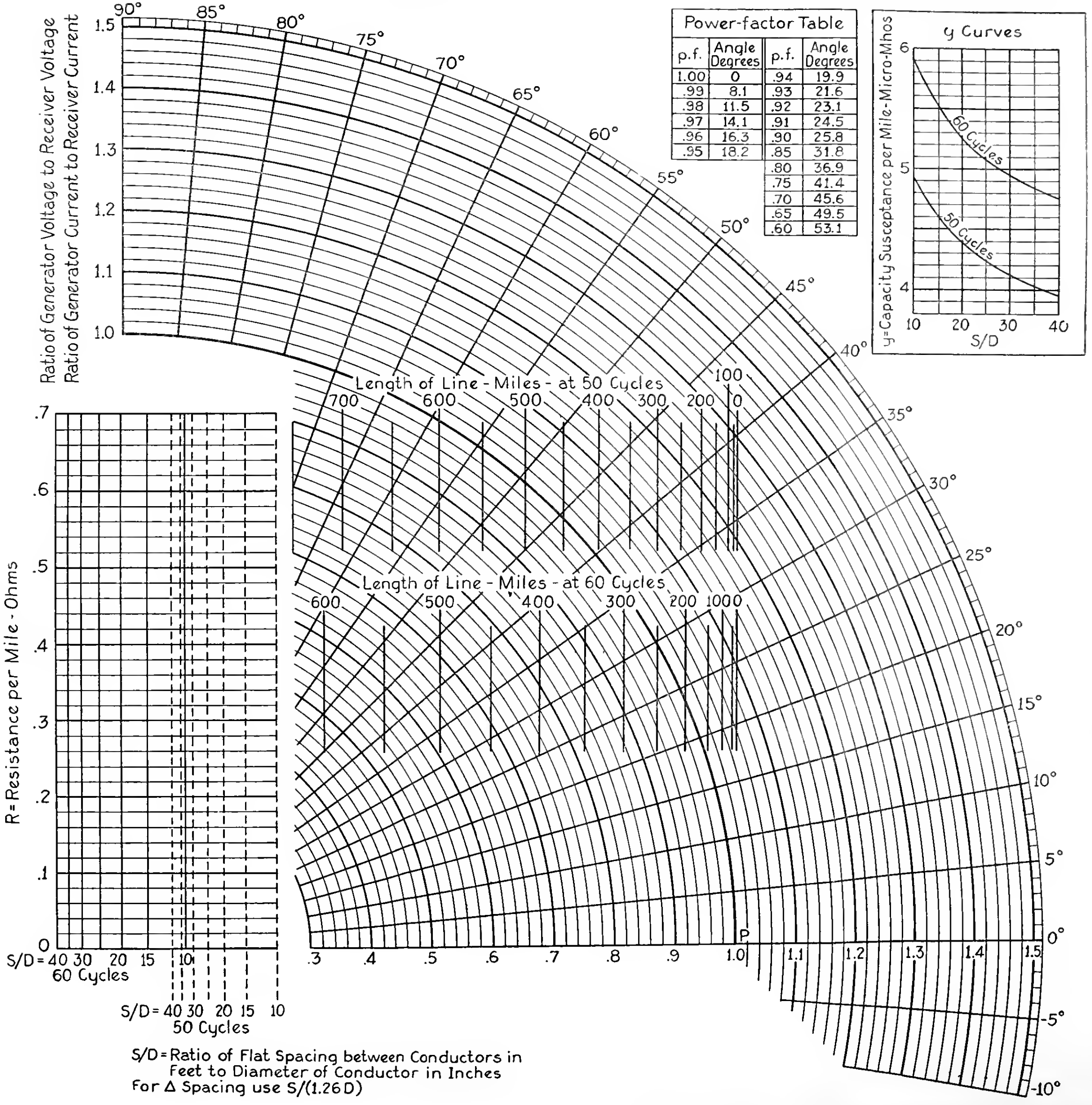
*Appears in G. E. Review, June, 1923, page 387.



S/D = Ratio of Flat Spacing between Conductors in Feet to Diameter of Conductor in Inches
For Δ Spacing use S/(1.26 D)

Power-factor Table

p.f.	Angle Degrees	p.f.	Angle Degrees
1.00	0	.94	19.9
.99	8.1	.93	21.6
.98	11.5	.92	23.1
.97	14.1	.91	24.5
.96	16.3	.90	25.8
.95	18.2	.85	31.8
		.80	36.9
		.75	41.4
		.70	45.6
		.65	49.5
		.60	53.1

Q Table

Length of Line Miles	Frequency	
	50 Cycles	60 Cycles
0	0	0
50	.0499	.0499
100	.0995	.0993
150	.1484	.1476
200	.1961	.1944
250	.2424	.2390
300	.2869	.2812
350	.3294	.3205
400	.369	.356
450	.407	.388
500	.441	.416
550	.472	.440
600	.500	.459
650	.524	
700	.544	
750	.560	

θ Table
θ in Degrees
For R = 1 Ohm per Mile

Length of Line Miles	Frequency	
	50 Cycles	60 Cycles
0	0	0
50	0.2	0.2
100	0.4	0.5
150	0.9	1.2
200	1.7	2.0
250	2.7	3.2
300	3.8	4.6
350	5.2	6.3
400	6.9	8.3
450	8.7	10.7
500	10.9	13.4
550	13.4	16.5
600	16.2	20.1
650	19.0	
700	22.8	
750	26.6	

A Transmission Line Calculator

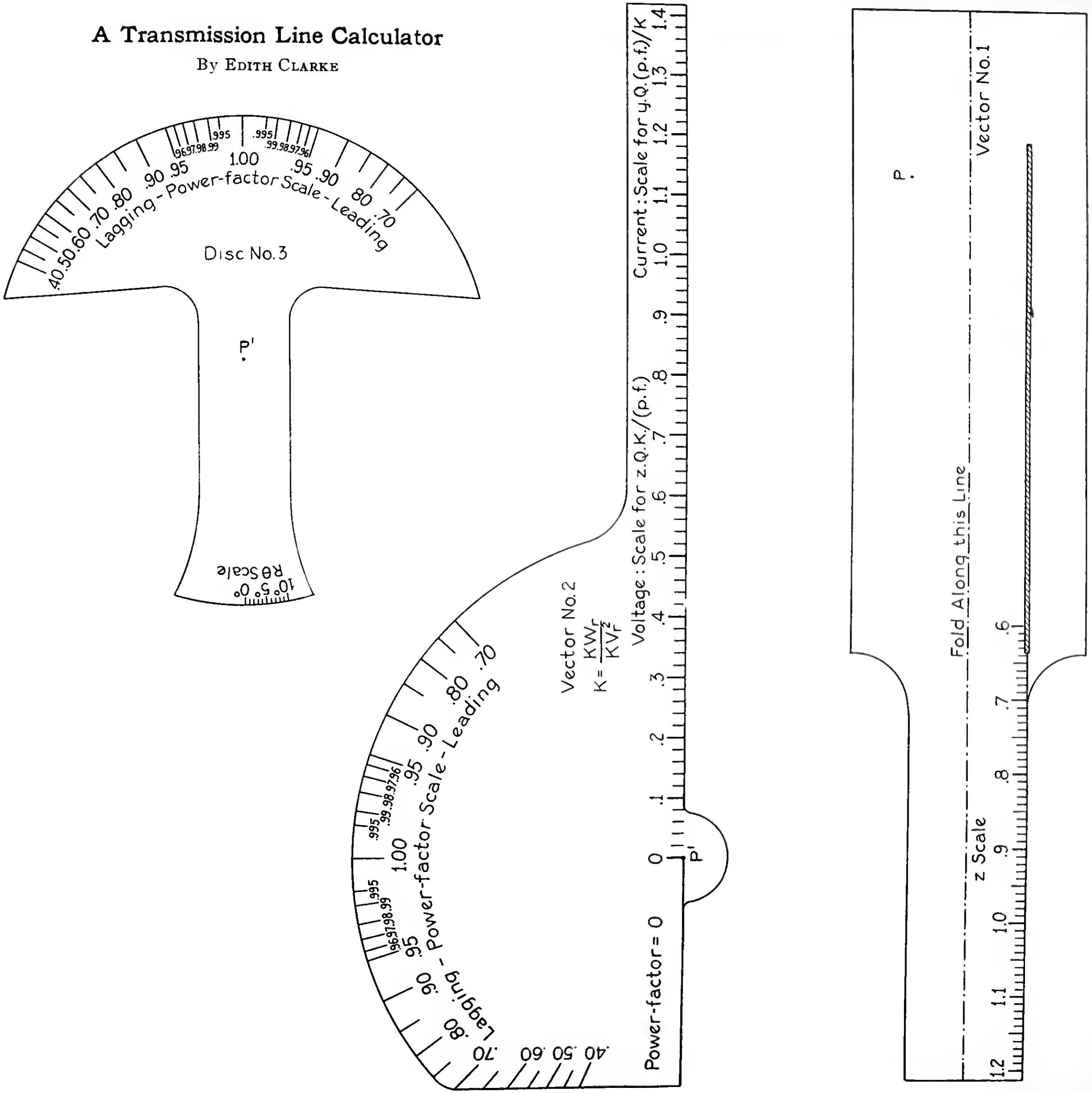
By Edith Clarke

TRANSMISSION LINE CALCULATOR DIRECTIONS FOR ASSEMBLING

If this working model of the Transmission Line Calculator is carefully assembled, it may be used to advantage in preliminary calculations to obtain the voltage, current, power-factor and power at the generator end of a transmission line when the voltage, load and power-factor at the receiver end are known. If mechanically correct, it will give results without appreciable error for lines up to 250 miles in length at 60 cycles, 300 miles at 50 cycles or 600 miles at 25 cycles. For lines 400 miles in length at 60 cycles the error may be about 1 per cent. The error increases with the length of line, but even at the extreme range of the Calculator it will not be more than about 2 per cent for voltage and current values. Since the power at the generator end is obtained from the product of voltage and current, the error in the power may be twice as large as that in voltage or current. In general, the values calculated on the Transmission Line Calculator are high rather than low.

Cut out the three parts given on this sheet. For a more substantial calculator, paste them, and also the Base Chart of Supplement I (entire sheet) on cardboard. Cut out the narrow crossed hatched band of Vector No. 1, then fold along the dotted line. Pivot Vector No. 1 at point *P* of the Base Chart, with point *P* of the Vector above point *P* of the Base Chart. A thumb tack will do very well as a pivot if the point of the tack is cut off after it is in place and a metal washer soldered on. This pivot at point *P* must be flat so that the pivot of Vector No. 2 may slide over it for short-line settings. Place the center, *P'*, of Disc No. 3 over the center, *P'*, of the circular head of Vector No. 2. This common center, *P'*, must be made to slide along the center line of Vector No. 1 in the groove cut out for that purpose, and Disc No. 3 and Vector No. 2 must be free to rotate about it. A second thumb tack will do for this pivot and sliding point. Place the thumb tack in the groove of Vector No. 1, with its point upward. Glue the under and upper parts of Vector No. 1 together in such a manner that the thumb tack is not impeded when sliding in the groove. Force the point of the thumb tack through the center, *P'*, of the circular head of Vector No. 2 and the center, *P'*, of Disc No. 3. A second metal washer may be soldered on to keep Vector No. 2 and Disc No. 3 in place.

The Calculator is now ready for use. Directions for use are given on the Base Chart of Supplement I.



by Q.

$I_g = \frac{KV_r}{\sqrt{3}}\, y\, Q$. Where y, the capacity susceptance per mile in micro-mhos, corresponding to S/D and given frequency, is taken from the "y Curves," and Q corresponding to given frequency and length of line, is taken from the "Q Table."

Short Circuit at Receiver End

For short circuit at the receiver end, from equation (1) and (2) by substituting zero for e_r

$$e_g = I_r\, Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\ldots\right)$$

$$I_g = I_r\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$

TABLE III

FOUR ASSUMED TRANSMISSION LINES AND CONDITIONS AT THE RECEIVER ENDS

Conditions	Line 1	Line 2	Line 3	Line 4
f (cycles)	60	25	50	60
l (miles)	125	300	750	150
Material	Copper	Aluminum steel core	Aluminum steel core	Aluminum steel core
Size	No. 00	510,000 cm.	950,000 cm.	605,000 cm.
D (inches)	0.420	0.885	1.194	Split conductor, 9 wires.
S (feet)	10	21	22	Assume: $X=0.495$ ohms/mile $y=8.58$ micro-mhos/mile
R (ohms/mile)	0.4108	0.1704	0.0916	⅓ (0.144) =0.048
KV_r (kv.)	100	200	220	250
KW_r (kw.)	20,000	80,000	115,000	400,000
$p.f.$ of load	0.75 lag	0.75 lag	0.80 lag	0.85 lag
$(p.f.)_r$	0.98 lag	0.98 lag	0.95 lag	1.00
KV-A, leading (kv-a.)	13,600	54,300	124,000	248,000

from which it follows that

$$I_r = \frac{e_g}{Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+.\right)} = \frac{KV_g}{\sqrt{3}\, z\, Q}$$

$$I_g/I_r = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\ldots\right)$$

$$= E_g/E_r \text{ at no load}$$

$$I_g = \frac{KV_g}{\sqrt{3}\, z\, Q} \quad (E_g/E_r \text{ at no load})$$

Split Conductor

Lines of the split conductor type proposed by Mr. Percy Thomas* can be solved on the Calculator when X and y are known. $z=\sqrt{R^2+X^2}$ is calculated, and Vector No. 1 is given the proper slope by making it the hypotenuse of a triangle having sides, $-X$ and R, laid off to any convenient scale. The procedure is then the same as with any other three-phase transmission line.

Frequency

The Calculator given in Supplement I is designed for transmission lines with frequencies of 50 and 60 cycles, but it can be used for lines of any frequency. A new resistance, $R' = R\,\frac{50}{f}$, and a new length of line, $l' = l\,\frac{f}{50}$, are calculated; then the line is treated as though it were a 50-cycle line having a resistance of R' and a length of l'.

The above statement is apparent from equations (3) and (4), if the following substitutions are made for Z and Y:

$$Z = lz = l\,(R+jX) = fl\left(\frac{R}{f}+j\,2\pi\,L\right)$$

$$Y = ly = l(\quad +jy) = fl\,(\quad +j\,2\pi\,C)$$

Since L and C are uniquely determined for a given value of S/D, the number of independent variables on the right-hand sides of equations (3) and (4) may be reduced to five. They are fl, R/f, S/D, K and $(p.f.)_r$. Two lines of different length, frequency, resistance, spacing between conductors and size of conductors, operated at different voltages and delivering different amounts of power will have the same drop in voltage from the generator end to the receiver end and the same per cent power loss if fl, R/f, S/D, K and $(p.f.)_r$ are the same in the two cases. Two such lines are given below:

1. 3-phase, 60-cycle, 125-mile line of No. 00 copper, flat spacing between conductors of 10 feet, $KV_r=100$ kv., $KW_r=25{,}000$ kw., $(p.f.)_r=0.90$ lagging.
2. phase, 3-25-cycle, 300-mile line of 510,000 c.m. steel re-enforced aluminum, flat spacing between conductors of 21 ft., $KV_r=200$ kv., $KW_r=100{,}000$ kw., $(p.f.)_r=0.90$ lagging.

	Case 1	Case 2
fl	$60\times125=7500$	$25\times300=7500$
R/f	$0.41/60=.00683$	$0.17/25=0.00680$
S/D	$10/0.42=23.8$	$21/0.885=23.7$
K	$25{,}000/100^2=2.5$	$100{,}000/200^2=2.5$
$(p.f.)_r$	0.90 lagging	0.90 lagging.

For these two lines, E_g/E_r, I_g/I_r and KW_g/KW_r will be the same.

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* Transactions of the A.I.E.E., June 29, 1909.

Twenty-five Cycles

It was not found necessary to design the Calculator for a frequency of 25 cycles, since it is such a simple matter to calculate a 25-cycle line on the 50-cycle calculator. The resistance used must be twice the given resistance and the length of line one-half the given length, but otherwise, the procedure is the same as though the frequency were 50 cycles instead of 25 cycles.

EXAMPLES

In order to illustrate the use of the Calculator, four high-voltage transmission lines will be selected and the conditions at the receiver ends assumed. Following the directions given on Supplement I, conditions at the generator ends of these lines will be calculated on the Calculator, and each step of the procedure, as well as the final results, will be given.

The assumed transmission lines and conditions at the receiver ends are given in Table III.

The calculations of conditions at the generator ends of the assumed transmission lines by means of the Transmission Line Calculator, following the directions given on Supplement I, are given in Table IV.

TABLE IV

CALCULATED CONDITIONS AT GENERATOR ENDS OF THE ASSUMED TRANSMISSION LINES BY MEANS OF THE TRANSMISSION LINE CALCULATOR

Conditions	Line 1	Line 2	Line 3	Line 4
S (feet)	10	21	22	Assumed value of
D (inches)	0.420	0.885	1.194	$X = 0.495$
S/D	23.8	23.7	18.4	
f (cycles)	60	25	50	60
R (ohms/mile)	0.4108	0.1704	0.0916	0.048
$R' = R\frac{50}{f}$	....	0.341	....	....
Vector No. 1 is set for S/D and R. (R' for 25 cycles). For Line 4, Vector No. 1 is given slope $R/-X$.				
z (from "z Scale" of Vector No. 1)	0.925	0.770	0.670	$z = \sqrt{R^2+X^2} = 0.497$
l(miles)	125	300	750	150
$l' = l\frac{f}{50}$	....	150	....	....
Pivot of Vector No. 2 is moved along Vector No. 1 and set for l. (l' for 25 cycles.)				
VOLTAGE				
$(p.f.)_r$	0.98 lag	0.98 lag	0.95 lead	1.00
Vector No. 2 is rotated about its pivot and set for $(p.f.)_r$				
θ (from "θ Table")	0.8	1.0	26.6	Neglect
$R\ \theta$ (degrees)	0.33	0.34	2.44	Neglect
Slope of Vector No. 2 is corrected by rotating it counter-clockwise through the angle $R\ \theta$.				
Q (from "Q Table")	0.1234	0.1484	0.560	0.1476
KW_r (kw.)	20,000	80,000	115,000	400,000
KV_r (kv.)	100	200	220	250
$K = KW_r/KV_r^2$	2.0	2.0	2.38	6.40
$KQ\ z/(p.f.)_r$	0.233	0.233	0.940	0.470
With Load:—$KQz/(p.f.)_r$ is laid off along Vector No. 2, and Eg/E_r is read on Base Chart under this point.				
Eg/E_r (Magnitude)	1.125	1.125	1.015	1.103
Eg/E_r (angle°)	10.1	10.1	86.0	25.3
$KVg = KV_r(Eg/E_r)$	112.5	225	223	276
No Load; No Condenser:—Eg/E_r is read under pivot of Vector No. 2.				
Eg/E_r	0.967	0.967	0.29	0.953
$KVg = KV_r(Eg/E_r)$	96.7	193.4	63.7	238.0
No Load; Condenser Taking Lagging Current:				
$KV\text{-}A_c$ lagging. 75 per cent of leading kv-a.	10,200	40,800	93,000	186,000
$K' = KV\text{-}A_c/KV^2_r$	1.02	1.02	1.925	2.97
$K'Qz$	0.1167	0.1167	0.723	0.218
VOLTAGE—Continued				
Vector No. 2 is rotated about its pivot and set for $p.f. = 0$ $K'Qz$ is laid off along Vector No. 2 and Eg/E_r is read on Base Chart under this point.				
Eg/E_r (magnitude)	1.072	1.072	0.995	1.170
Eg/E_r (angle°)	—1.8	—1.8	+0.9	—0.8
$KVg = KV_r(Eg/E_r)$	107.2	214.4	219	292
CURRENT				
Disc No. 3 is rotated about its pivot and set with unity $p.f.$ line vertical. Vector No. 2 is rotated about its pivot and set to coincide with given $(p.f.)$ line of disc No. 3. Slope of Vector No. 2 is corrected by rotating it counter-clockwise through angle $R\ \theta$.				
y (from "y" Curves")	5.12	4.27	4.44	8.58
$y\ Q\ (p.f.)_r/K$	0.310	0.310	0.992	0.198
With Load:—$y\ Q\ (p.f.)_r/K$ is laid off along Vector No. 2 and Ig/I_r is read on Base Chart under this point.				
Ig/I_r (magnitude)	0.959	0.959	1.180	0.974
Ig/I_r (angle°)	19.3	19.3	62.6	12.0
$I_r = \frac{KW_r}{\sqrt{3}\ KV_r(p.f.)_r}$	117.8	235.6	317.5	923.0
$Ig = I_r\ (Ig/I_r)$	113	226	375	900
Charging Current; Open Circuit:				
$Ig = \frac{KV_r}{\sqrt{3}}\ y\ Q$	36.5	73.0	316.0	183.0
GENERATOR POWER-FACTOR				
$\phi_r = \cos^{-1}(p.f.)_r$	—11.5	—11.5	+18.2	0
$\phi g = (\text{angle } Ig/I_r - \text{angle } Eg/E_r \pm \phi_r)$	—2.5	—2.5	—5.2	—13.3
$(p.f.)g = \cos\ \phi_g$	0.999 lag	0.999 lag	0.996 lag	0.973 lag
POWER				
$KWg/KW_r = \left(\frac{Eg}{E_r}\right)\left(\frac{Ig}{I_r}\right)\frac{(p.f.)g}{(p.f.)_r}$	1.10	1.10	1.26	1.045
$KWg = KW_r \times (KWg/KW_r)$	22,000	88,000	145,000	418,000

Alternating-current Secondary Networks

By D. K. Blake

Lighting Engineering Department, General Electric Company

Great attention has been paid to every detail of power station and substation equipment and also to the details of transmission lines, but in the past such minute study has not been given to the distribution system. The author takes up this study and treats it in detail in a way that should be of interest to those responsible for the distribution of electric energy.—Editor.

During the past few years, the engineers of central station companies have given more attention to their alternating-current distributing system than previously. It is being recognized that, since the investment in the distribution system is a very large part of the total investment, large economies are possible. Changes and expansions based upon economic studies by different engineers have produced surprising economies. Some of the results usually obtained are less primary copper; fewer but larger transformers, with the consequent increase in load factor and efficiency; decrease in core loss per kv-a.; less investment per kv-a.; and less investment in lightning arresters, where they are used at each transformer location; and smaller difference between substation watthour meters and consumers' watthour meters.

One company, upon investigating a certain section of its distribution system containing approximately 3000 transformers, found that the average size of transformers was approximately 12 kv-a. with a transformer load factor of 11 per cent. Improvements made in the system brought the average size up to approximately 26 kv-a. with a load factor of approximately 18 per cent.

The distribution systems which now exist in most American cities consist of direct current substations supplying an Edison three-wire network for the business section, and transformer substations supplying 2300-volt or 4000Y-volt, three-phase radial feeders with distribution transformers, for other sections. For lighting loads, the secondaries of the distribution transformers supply approximately 115/230 volt, three-wire mains, which usually are not interconnected, as shown in Fig. 1. For power loads, three-phase banks are installed for low voltage motors. The expanding business sections make it necessary to extend the Edison network, or carry part of the business section on a-c. feeders. The investment and energy losses in substation equipment and low voltage feeders make it uneconomical and undesirable to extend the Edison network. Some companies have installed a-c. secondary networks in place of extending the Edison network. Many other companies are now considering the use of secondary networks to prevent extending the Edison network. One company in a large eastern city and a few smaller companies are considering replacing their Edison system with a-c. secondary networks. Secondary networks on existing single-phase, three-wire, secondary distributing systems are formed by connecting the secondary mains of each transformer on the same phase together, as shown by the dotted lines in Fig. 1.

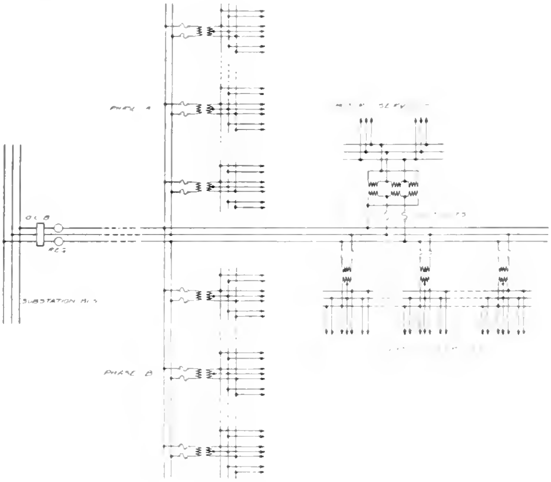

Fig. 1. Typical Three-phase Feeder

There are several factors which make the secondary network more economical and desirable than the method of supplying groups of consumers from a single transformer. With a network it is possible to reduce the total transformer kv-a. capacity installed and increase the transformer load factor due to the diversity of loads between transformers. Large size transformers may be used which have a lower cost per kv-a. than small transformers. These two factors reduce the transformer investment and installation costs. Large size transformers also have a lower core loss per kv-a. and a higher efficiency than small ones. The ability to supply customers from two or more directions and the diversity between customers reduces the secondary copper losses, and improves the voltage regulation and also assists in giving continuous service which results in increased wattage consumption on resistance loads with increased revenue. Reductions are also possible in primary copper losses and investment, particularly where the three-phase four-wire primary system is used with the same neutral wire for the primary and secondary. With a well designed secondary network the difference between the consumers' watthour meters and the feeder watthour meters is a minimum. Increase in loads may be taken care of with greater ease and economy. The number of points of inspection on a secondary network are a minimum which is quite an advantage, particularly in case of trouble.

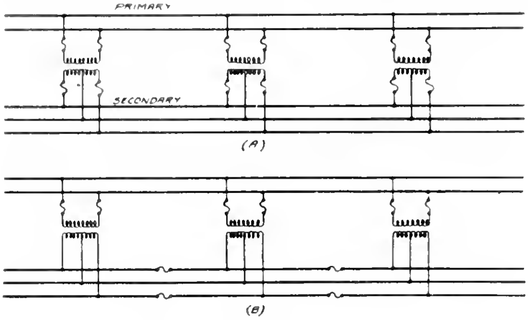

Fig. 2. Transformers in Network Protected with Fuses

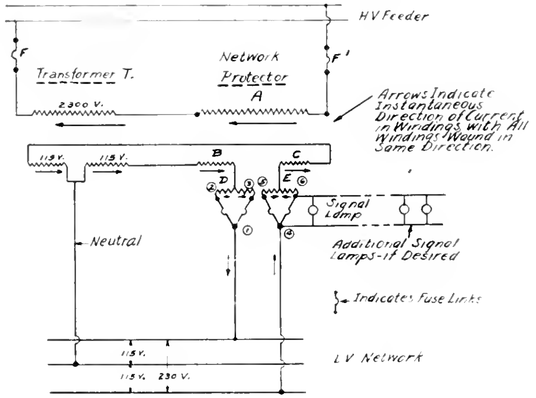

Fig. 3. The Alternating-current Network Protector

The successful design and operation of secondary networks presents many interesting and complex problems. Chief among these are the short circuit protection of primary mains and transformers, the division of loads between transformers, supplying motor loads and the choice of the type of system to use.

Fuses have been used to a large extent for short circuit protection of transformers. The methods generally used are shown in Fig. 2. The primary fuses are selected for operation on short circuits and the secondary fuses are selected to operate after the primary fuse. The transformers should not be fused for overload protection since the losing of one transformer, due to overload, shifts the overload to adjacent transformers which also may be overloaded, thereby blowing their fuses. This action in scheme (a) may proceed until all transformer fuses on the network are blown. Overloads usually occur at or near peak load on the network. Therefore, it is a very serious matter to have an interruption at this time. It requires considerable effort and time to restore an interrupted network protected with fuses. The scheme shown at (b) protects the secondary mains also. In a network of any size it is unnecessary to have short circuit protection on secondary mains, since it has been found that any short circuit will burn itself clear as in a d-c. network. Fairly good results have been obtained with fuses, but the best of them do not meet the requirements of most engineers.

Fig. 4. Assembly of Core and Coils of a 50-kv-a. Subway Transformer Equipped with Network Protector; High-voltage Side

Some companies are now using the a-c. network protector, which is shown in Fig. 3. The coils A, B, C, D and E are wound on the same iron core. The arrows indicate the flow of current with the transformer carrying load. The ampere turns of B and C are equal and their sum is equal and opposite to the ampere turns of A. They, therefore, have no magnetic effect on the iron core. In coils D and E the current enters at the center and divides equally. Since the turns are wound in the same direction in each coil, the ampere turns of one half neutralize the ampere turns of the other half. Under normal conditions, the core is not excited and no voltage is generated in coils D and E. If a breakdown or short circuit should occur in the transformer the current through B and C will be reversed. Under this condition the ampere turns of A, B and C act in the same direction and produce a magnetic flux in the iron core. The flux in the core induces a voltage in coils D and E. The voltages across these coils are short circuited through the fuse links. The large currents which circulate through 1-2-3 and 4-5-6 blow the fuses almost instantaneously, thereby disconnecting the secondary of the transformer from the network. The primary fuses blow practically simultaneously with the secondary fuses. The secondary fuses are designed so as not to operate under load conditions. The signal lamp is lighted when the fuse, across which it is connected, blows. This gives a reliable indication of the transformer disconnected from the network.

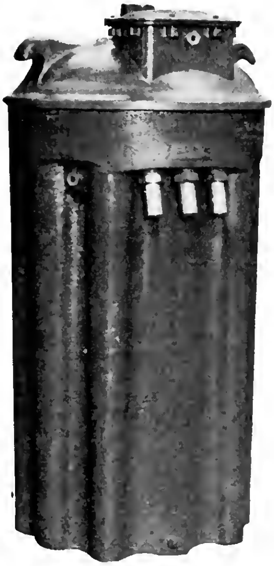

Fig. 5. 50-kv-a. Transformer Equipped with Network Protector, Complete Assembly, Low-voltage Side

Fig. 6. 50-kv-a. Transformer Equipped with Network Protector View of Cover and Fuse Board

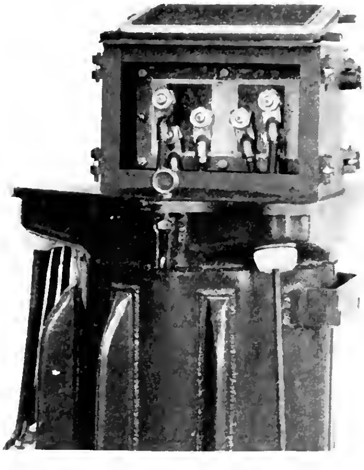

Fig. 7. Model of Network Protector, Cover Removed Showing Leads

The network protector is now made as a part of the transformer, which simplifies the wiring and installation, as shown in Fig. 4 The coils are assembled about the middle leg of a three legged core which is firmly mounted in clamps and supported under the oil at about the same place inside the transformer tank that the lead supports ordinarily come. To eliminate possible damage which might result from the explosion of the fuse links over the oil, they are placed in a separate compartment formed in the transformer cover, as shown in Figs. 5, 6, 7 and 8. The fuse links are located so that the blowing of one link will ensure the blowing of the other. The signal lamp provided is located inside the fuse chamber behind the bull's eye, as shown in Figs. 6 and 7, so that in dark manholes or at night there can be no doubt as to the transformer disconnected. The fuse chamber is arranged for a conduit connection so that additional signal lamps may be connected and located on lamp posts above the street level or on poles, or carried to some convenient place where patrolmen can notice immediately any transformer which may be cut off from the network. On networks large transformer units are used with relatively few sizes. The protector, therefore, has been standardized for 50, 75 and 100-kv-a., 2300 to 115/230-volt, 60-cycle transformers for either pole or subway operation. It can be developed for higher voltage circuits or for polyphase transformers and networks. The vertical terminal board is standard for transformers of 50, 75 and 100 kv-a. in the pole type and for 75 and 100 kv-a. in the subway type. On subway transformers, the principal object in using the vertical terminal board on the larger sizes is to enable a man to work in the fuse chamber more conveniently. The low ceilings in many manholes would make this difficult with the larger sizes of transformers. The layout of a 2400-volt, two-phase primary, 120/240-volt, single-phase, three-wire secondary underground network, using network protectors, is shown in Fig. 9.

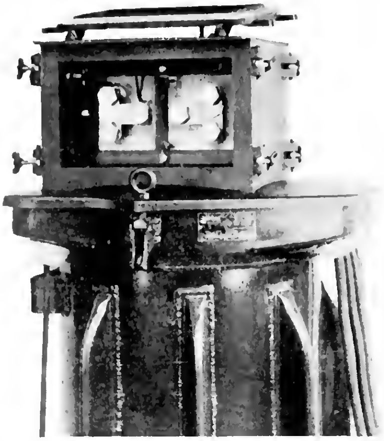

Fig. 8. Model of Network Protector, Cover Removed Showing Connections

The United Electric Light and Power Company of New York City are now using a reverse energy device which permits the use of a network supplied by multiple feeders, as shown in Fig. 11, instead of having a small network for each radial feeder, as shown in Fig. 10. The device consists of an air circuit breaker, no-voltage relay, reverse energy relay and reactive shunt, all of which are mounted on a panel. A diagram of connections is shown in Fig. 12. Normally the circuit breaker is closed with the transformer supplying current to the network. The breaker is held closed by means of a latch. The current flowing through the reverse energy relay holds the lower contacts of the relay closed. When power flows from the network to the transformer, the reverse energy relay opens its lower and closes its upper contacts. The closing of the upper contacts shunts the no-voltage relay coil, thereby tripping the breaker. With no voltage applied to the primary of the step-down transformer, the upper contacts of the reverse energy relay remain closed because of the current which flows through the difference of potential coils. The circuit of the difference of potential coils is completed through the secondary of the transformer. The small current which flows does not have an appreciable magnetizing effect on the transformer. When approximately normal voltage is applied to the primary, the voltage opposes the network voltage applied to the difference of potential coils, with the result that the lower contacts of the relay shunt the resistor which permits full secondary voltage to be applied to the no-voltage relay. The closing of the contacts of the no-voltage relay energizes the closing coil of the air circuit breaker which closes the breaker, thereby connecting the transformer to the network.

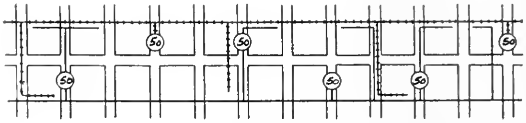

Fig. 9. Alternating-current Network Using Network Protectors

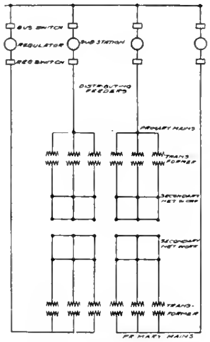

Fig. 10. Networks on Radial Feeders

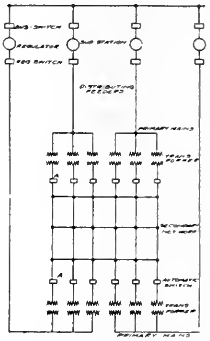

Fig. 11. Multiple Operation of Primary Feeders

By referring to Fig. 11, it will be seen that if a fault should occur in the transformers or primary mains and feeders, the device A will clear the transformers of the feeder in trouble from the network and the feeder breaker at the substation bus will open. The other feeders will carry the network load without an interruption to service. When the fault is repaired the breaker at the substation is closed and the air circuit breakers automatically close, connecting the transformers to the network. During periods of light load the circuit breakers of one or more feeders may be opened, in which case the exciting current supplied to the transformers from the network is sufficient to trip the breakers and disconnect the transformers from the network. This permits removing a feeder for repairs and a saving in core loss with the consequent increase in the light load efficiency of the network. The operation of the device on the exciting current of the transformer is accomplished by the reactive shunt. The shunt consists of one turn of copper around an iron core. The core becomes saturated at low values of current with the result that at normal load current, the ordinary 5 ampere relay coil is not overheated. The device is arranged for basement or vault mounting. It is protected from water by means of a bell which fits over the device and is sealed at the bottom. In case the seal should break, the water is prevented from covering the apparatus by the compression of the air in the bell. The load densities on the networks range from 100 kw. per block to 400 kw. per block. The networks are supplied from two or more substations with no less than a total of eight primary feeders. The transformers per feeder range from 5 to 20 transformers.

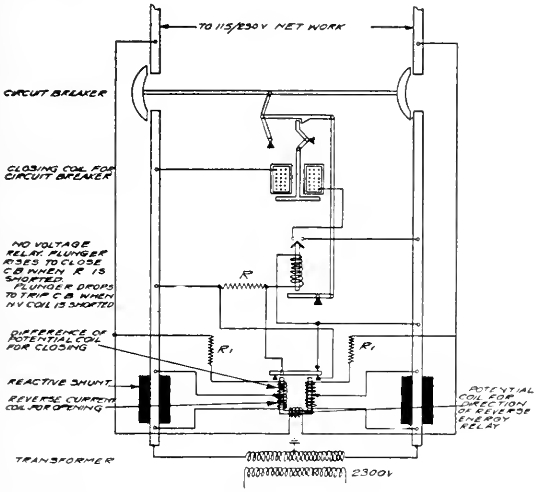

Fig. 12. Air Circuit Breaker with Reverse-current Trip

Oil circuit breakers with reverse power relays are being used to some extent. Mr. M. T. Crawford, in the *Electrical World* of December 23, 1922, describes a scheme used by the Puget Sound Power and Light Company in Seattle. A diagram of connections is shown in Fig. 13. In case of transformer trouble the reverse power relay trips the secondary oil circuit breaker and the primary fuses blow. In case of primary feeder or main trouble the substation oil circuit breaker and the secondary oil circuit breakers of the transformers, connected to the phases of the feeder in trouble, will open. The load on the secondary network will be carried by the other feeder or feeders. Any number of feeders or transformers per feeder may be used. In sections where the power load is dense, small power secondary networks supplied from the same primary feeders are formed.

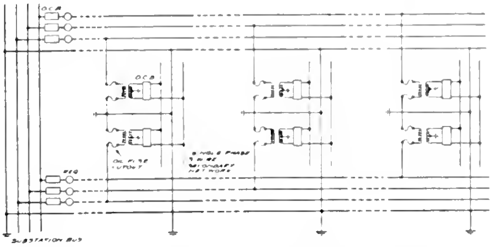

Fig. 13. Protection of Transformers Connected to Secondary Networks with Oil Circuit Breakers and Reverse-power Relays

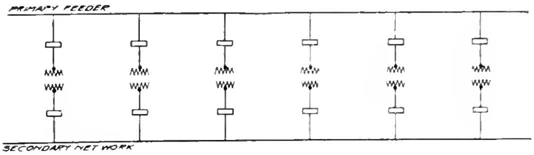

Fig. 14. Differential Protection of Transformers

The use of oil circuit breakers connected in the primary and secondary circuits of the transformers, as shown in Fig. 14, is under consideration by several companies. Current transformers in the primary and secondary will have their secondaries connected in series with trip coils connected across the current transformers to give differential protection. The breakers will open automatically only when trouble occurs in the transformers. Circuit breakers for this purpose are being developed with the two-pole breaker for the 2500-volt primary, two-pole breaker for the 230-volt secondary, and current transformers assembled in one unit for use in vaults. The mechanism will be arranged so that both breakers will trip simultaneously on automatic operation, but either the primary or secondary breaker may be opened or closed by hand independently of the other.

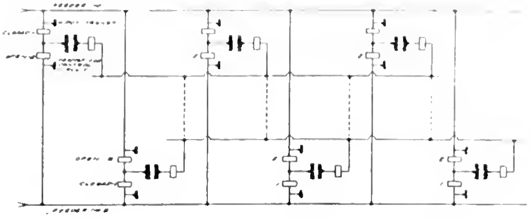

Fig. 15. Automatic Throw-over Circuit Breakers

Practically all applications of oil circuit breakers to distribution networks are limited to districts with very high load densities. Several schemes using oil circuit breakers with relays have been suggested for downtown business sections. A scheme for automatically transferring transformers from one feeder when its voltage fails to a good feeder is shown in Fig. 15. If the station oil circuit breakers of feeder No. 1 should open, then the transformer oil circuit breakers, which are normally closed, will open, and the breakers normally open will close and connect the transformers to feeder No. 2. The control circuits of the breakers are shown in Fig. 16. The potential relay with time delay opening is connected to the line side of the oil circuit breaker No. 1 through a potential transformer. Under normal operating conditions, the upper contacts of the potential relay are closed. When the voltage of feeder No. 1 falls below its adjustment, the lower contacts close. Oil circuit breaker No. 1 is then tripped by its trip coil. The opening of No. 1 breaker closes its auxiliary switch (b) which completes the operating motor circuit of breaker No. 2, thereby closing breaker No. 2. Feeder No. 2 then carries the transformers of feeder No. 1. When voltage is restored to feeder No. 1, the potential relay closes its upper contacts which trip circuit breaker No. 2. The opening of circuit breaker No. 2 completes the operating motor circuit of breaker No. 1, thereby restoring the transformers to their original feeder. If the transformers on each feeder are connected to form a network, the network protector may be used to clear the transformer, or an oil circuit breaker may be installed in the secondary with current transformers in the primary and secondary differentially connected to trip all three breakers in case of transformer failure. If the networks are tied together, as shown by the dotted lines in Fig. 15, a complete interruption to both feeders may result in case of a fault on one feeder, unless the potential relay has an inverse time characteristic sufficient to let the feeder with the lower voltage clear first. If the line breakers are equipped with reverse power relays instead of the voltage relay, both feeders could be tied together at each transformer. In case of trouble on any one feeder, the reverse power relays would clear the transformers from that feeder. Service on the network will be maintained by the other feeder. Transformer trouble as in the previous case would be cleared by network protectors or differential protection. The network may be supplied by more than two feeders if required.

A network supplied by loop feeders is shown in Fig. 17. The feeders may be protected by inverse time limit overload relays at the station with reverse power relays at the breaker connecting the feeder to the mains, or pilot wire protection. With the breakers in the mains equipped with reverse power relays, it is necessary to give alternate breakers graded current and time settings to prevent improper relay operation. The settings would be graded as shown by the numbers below the breakers. With the pilot wire protection, no grading is necessary, since the breakers can only trip in case of trouble on the main in which they are connected. Under normal

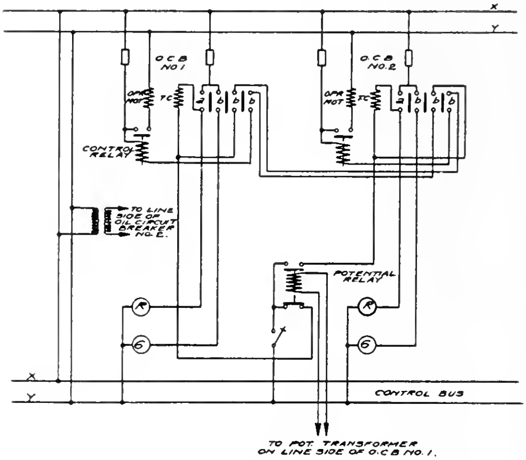

Fig. 16. Control Circuits for Automatic Throw-over Oil Circuit Breakers

conditions, the secondary current of the current transformers circulates through the pilot wires. When a fault occurs in the main, the secondary current of each current transformer is forced through the relay equipment connected to it. The relays trip the breakers at each end, thereby clearing the fault from the system. The pilot wires should be run in a separate cable and duct. A multi-conductor cable can be used containing pilot wires for several feeders and other purposes. The presence of pilot wires in moderate or high voltage cables greatly increases the insulation stresses and interferes with the making of good joints. The insulation of the cable should be increased to take care of the increased stresses. The extra insulation reduces the maximum conductor size obtainable in multi-conductor cables because of the diameter of the cable being limited. A faulty transformer is removed from the system by the network protector or the differential connection of relays to trip a secondary breaker and the two breakers in the mains.

Where a-c. secondary networks are to be used in the downtown business sections of very large cities, it is desirable to use a higher primary voltage than 2300 volts or 4000 volts, because of the high load density. With 11,000 volts or 13,000 volts about one third as many feeders will be required because of the greater capacity per feeder. Large vaults spaced a few hundred feet apart will be required to ventilate the large transformers and to contain the protective equipment. Where the transformers must be installed in vaults which are not large enough to radiate the heat through the earth by natural radiation, other means of ventilation must be provided. The use of oil circuit breakers in vaults presents several difficult problems. The opening into the vault and the space available limit the overall dimensions of the breaker, thereby limiting the interrupting capacity obtainable. Means must be provided to conduct away the gases from the oil circuit breaker which may be generated when the breakers open under short circuit.

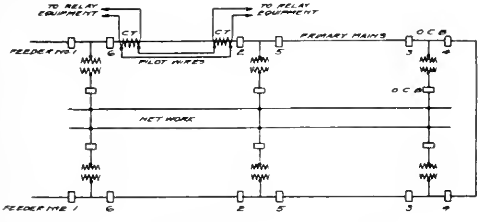

Fig. 17. Loop Feeders Supplying a Network

The cost of the vaults with the equipment and the difficulty of obtaining proper locations for vaults may, in some cases, make the scheme shown in Fig. 18 preferable. The network is supplied by a few substations containing large transformers of the power class. A large number of low voltage feeders connect each substation to the network. The transmission cables are protected with balanced connection of relays and the tie cables with reverse power relays. The transformers have standard differential relay protection. The feeders and mains would burn a fault clear as in a d-c. network. This scheme is practically the same as the Edison system, except that the converting equipment is replaced by the transformers. There are two important factors which make this scheme more economical than the Edison system, namely, the higher efficiency of transformation than conversion and the lower cost per kw. of the a-c. substation which in some cases, is about 65 per cent of the d-c. substation cost. *Similar schemes with three-phase, four-wire networks are in use in Europe and Australia. The voltage to neutral is about 200 volts and between phases 346 volts.

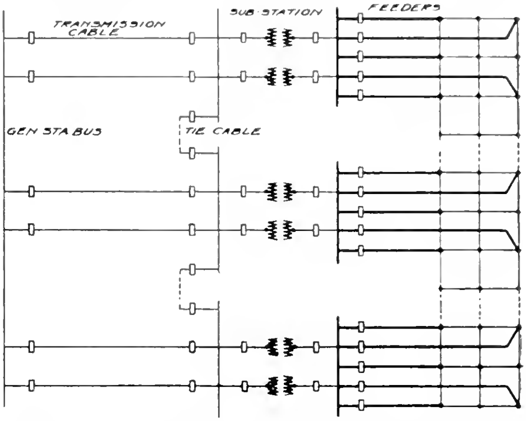

Fig. 18. Substations Feeding Directly Into Network with Low-voltage Feeders

The successful operation of a secondary network depends fundamentally on the proper division of load between the distribution transformers. Standard distribution transformers connected to a network, spaced several hundred feet apart, will not share their

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* "Review of Distribution Practice," by H. R. Summerhayes, G. E. REVIEW, March, 1914, and "The Dublin, Ireland, Three-phase Four-wire Distribution System," by Gilbert Archer, G. E. REVIEW, June, 1914.

loads according to their rating. If two transformers of equal rating are connected, as shown in Fig. 19, with the load concentrated at or beyond transformer No. 1, almost the entire load will be carried by No. 1 transformer. This is because the impedance of the secondary main is large compared with the impedance of the transformers. If the load is concentrated at the middle of the secondary main, then of course the load will be divided equally between the transformers.

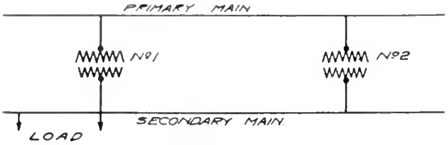

Fig. 19. Concentrated Load Connected to Network

If a transformer in a network is damaged by an overload, it will be cleared from the network by its protective equipment. The load carried by the transformer will then be transferred to the other transformers in the network. If standard transformers which have low reactance are used the adjacent transformers will carry the load of the faulty transformer. If the location of the faulty transformer is equi-distant from the adjacent transformers then they will divide the additional load approximately according to their rating, otherwise, the nearest transformer will take most of the load. The extra load carried by the adjacent transformers may be sufficient to burn out one or more transformers which will be cleared by their protective equipment. This action may proceed until the service to the entire network is interrupted. It is evident then, that some method must be used to force the transformers to divide the load according to their rating in addition to any protective device used to clear a damaged transformer from the network.

By increasing the reactance of both transformers in Fig. 19, transformer No. 2 will carry a larger proportion of the total load as shown by the curves in Fig. 20. The secondary mains are assumed to be 250 feet long for single-phase and 500 feet for three-phase with 4/0 wire mounted on 8-inch secondary brackets. The transformers are assumed to be one 75 kv-a. transformer for a single-phase network and three 50 kv-a. transformers for a three-phase network. If the impedance of the transformers is increased to 10 per cent, transformer No. 2 will carry 40 kv-a. when No. 1 is carrying 75 kv-a. in case of single-phase, or 55 kv-a. when No. 1 is carrying 150 kv-a. in case of three-phase. A better division of load will be obtained in underground networks using multi-conductor cable due to the lower reactance of the cable. Since the loads on a network are not usually concentrated at the transformer but distributed along the mains, a better division of load will be obtained than that shown by the curves. The use of high reactance in series with the transformers will, therefore, greatly relieve the transformers adjacent to the damaged one by distributing a large part of its load over the transformers beyond the fault. This should prevent to a great extent the trouble experienced on networks after the loss of one or more transformers. The impedance of the transformers may be increased by external reactance connected in series with the transformer or by designing transformers with inherent high reactance for network operation. The latter has a much lower cost than the former.

Standard distribution transformers have approximately 1.5 per cent resistance drop and 4 per cent reactance drop. The following is a comparison of the regulation of transformers with 4 per cent reactance and 10 per cent reactance:

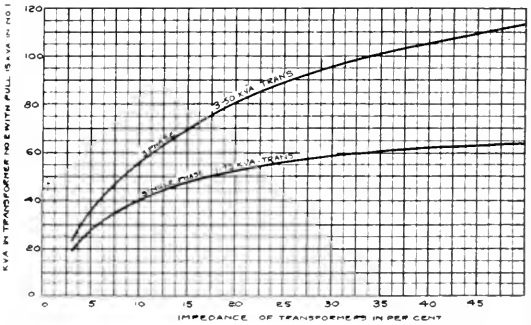

Fig. 20. Division of Load Between Transformers of Like Design

Per Cent Power-factor	PER CENT REGULATION		
	Per Cent $R=1.5$ $X=4$	Per Cent $R=1.5$ $X=10$	Difference
100	1.55	2	.45
95	2.8	5	2.2
90	3.2	6	2.8
85	3.5	6.9	3.4
80	3.7	7.4	3.7

It will be necessary to compensate for the extra regulation by means of the feeder regulators which, in some cases, may have to be increased in size. The curves show that not much is to be gained by increasing the impedance above 10 per cent for single-phase networks and 15 per cent for three-phase networks. The increased regulation may not permit the use of 15 per cent reactance.

Reactors may be connected in the secondary mains, instead of in series with the transformers, as shown in Fig. 21. Under normal conditions only a small current is carried by the reactor since most of the load on each section is supplied by its own transformer. If the distances between transformers are equal and the loads uniformly distributed, the load on section No. 5 will be supplied equally from transformers Nos. 2, 4, 6 and 8 without the use of reactors in case of the loss of transformer No. 5. Since the distances are not always equal, nor the loads uniformly distributed, the load will not be divided equally between the transformers. If the reactance of the mains between transformer No. 5 and No. 8 is 10 per cent and between No. 5 and No. 6 is 15 per cent, then the short main will carry 50 per cent more current than the long main when supplying load to section No. 5. If the reactors are rated at 25 per cent then the total reactance in the short main will be 35 per cent and the long main 40 per cent. Then the short main will only carry 11.4 per cent more current than the long main. The reactor therefore need only be designed for one quarter of the current rating of a transformer. The reactive drop with this current would then be 6.25 per cent. In case of a short circuit on any section, the reactors will maintain voltage on the adjoining sections.

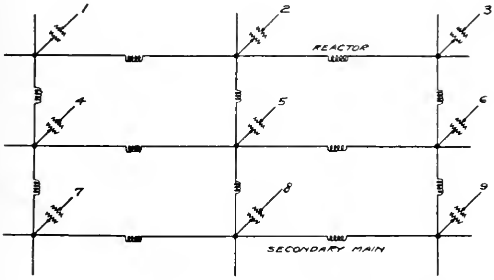

Fig. 21. Reactors Connected in Network Mains

There is at present under investigation a network system designed to compel an even division of load among the transformers, in spite of the usual uneven and irregular distribution of load on the secondary network. Reference to Fig. 22 will show the proposed arrangement, which consists of series balancing coils placed in the feeder at each transformer of the network, and so designed that they compel each transformer to take its proper share of the load regardless of where the load is located. The primary main between transformers T4 and T5 carries the current of T5 and T6 while the main T5-T6 carries the current of T6 only. If the transformers are of the same rating the turns of the auto-transformer E should be proportioned so that twice as many turns will be connected in the main T5-T6 as in T4-T5.

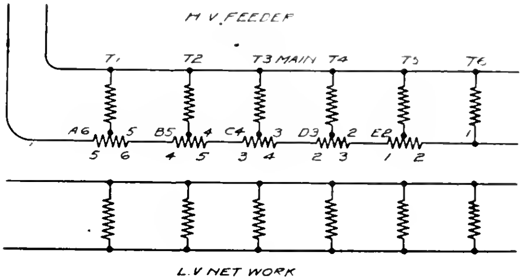

Fig. 22. Schematic Arrangement of Balanced Alternating-current Network

The numbers below the auto-transformer indicate the relative turns while the numbers above indicate the relative currents. The auto-transformers may consist of one coil in series with the feeder and one in series with the individual transformer, or of two coils in the feeder magnetically apposed and with the transformer connection brought off at a tap in the proper position.

This system will tend to avoid the difficulty commonly experienced with networks, that a heavy overload or short circuit will blow the fuses of adjacent transformers and extend the trouble to the entire network, by removing the transformers progressively from the line as the load is thrown on them. The transformers will all share an overload and the transformers adjacent to the overload will not take an undue proportion of it. In case of a short circuit, more energy will be supplied from the network as a whole, with the possibility of more rapidly burning off the fault.

It is evident that, since the current can flow in one direction only, loop primary circuits or feeders multipled on the primary side at other points than T1 cannot be used. Any number of feeders may be used with their transformers feeding into a common secondary network as shown in Fig. 23. A balance coil is connected in the mains at A to divide the load on each branch of the feeders.

A defective transformer on such a network may be removed from the system by simple fuses, since the remainder of the network will feed in sufficient current to blow the primary and secondary fuses on a defective unit without blowing the fuses of the adjacent transformers. When one transformer has been removed from the system, however, the balancing coils are no longer properly adjusted for their positions in the circuit, and an even distribution of load is no longer obtained. This condition may require special provision in the arrangement of the transformers or in protective apparatus. This feature and the desirable capacity in the balancing coils are being carefully studied. The capacity, of course, will be determined as a compromise between the cost of the apparatus and the extent to which it is desired to maintain an even division of load under extremely heavy overloads or short circuits.

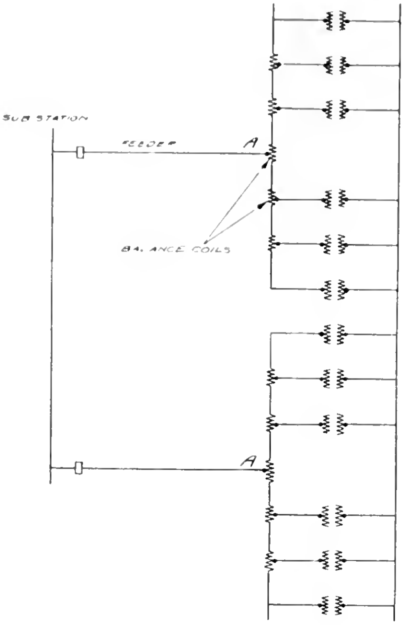

Fig. 23. Balanced Alternating-current Network with Multiple Feeders

The balancing coils under uniform distribution of load on the network do no work, and have no effect on the system except to introduce a negligible IR drop. When the load is unbalanced, however, the difference in drop between transformers supplying the load is taken up by the auto transformer, which under this condition develops a voltage across its terminals which is in such relation to the voltages within the feeder as to compel an approximately correct division of the currents. The balancing coil must be designed for the maximum voltage which would be required under unbalanced conditions.

The advantage expected from this system, in addition to those mentioned previously, are that it will permit a saving in transformer capacity over that ordinarily required to provide a margin for uneven distribution and local overloads. It should also tend to reduce copper losses by providing multiple paths for the supply of the load.

For the successful operation of feeders with induction regulators in parallel some modification may be necessary in the regulator control equipment. If both regulators are compensated to hold approximately normal voltage at the point B, Fig. 24, an increase in load may cause regulator No. 1 to increase its voltage before No. 2. If the reactance of the line is high with respect to the resistance a circulating current will flow which will be lagging almost 90 deg. the voltage of No. 1 regulator and leading almost 90 deg. the voltage of No. 2 regulator. The lagging current will cause regulator No. 1 to boost the voltage and the leading current through No. 2 will cause it to buck the voltage, both of which cause an increase in circulating current. This may progress until No. 1 regulator runs to full boost and No. 2 to full buck position. In this case the regulators are set to compensate for the entire reactance of the circuit. If the compensators are set to compensate to the point A for No. 1 feeder and the point C for No. 2 feeder then the portion A to C is not compensated for. In this case it will take a greater circulating current to run the regulators to the full buck and full boost position. Since the value of the circulating current

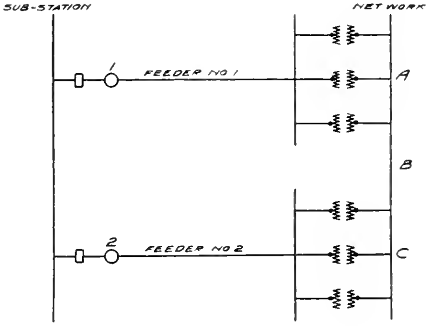

Fig. 24. Parallel Operation of Feeders with Induction Regulators

depends on the position of the regulators, it is obvious that the regulators will not take their limit positions, but will become stable at some intermediate point. This point will depend on the ratio of the reactance of the main between A and C to the reactance of the rest of the circuit.

The connections for the parallel operation of single-phase regulators is shown in Fig. 25. The current transformers connected in parallel are used with the line drop compensators to compensate for line drop. The current transformers connected in series are used to prevent circulating currents in the feeders. The reactance X may be a line drop compensator using both resistance and reactance where the resistance is appreciable. When a feeder is removed its current transformer used to prevent circulating currents should be short circuited by means of an auxiliary switch on the oil circuit breaker.

Most networks now in use are single-phase three-wire. Where the primary feeders are polyphase, the loads are balanced between the phases as nearly as possible with each phase supplying one or more small networks. This type of network will have many applications, particularly in residence sections with increasing appliance loads. Small single-phase motors used on appliances are supplied from the network, but any power loads within the district are supplied by separate transformers from the primary. The networks shown in Fig. 9 are supplied by a two-phase primary. In some blocks the phases are run parallel to each other to supply two-phase motors.

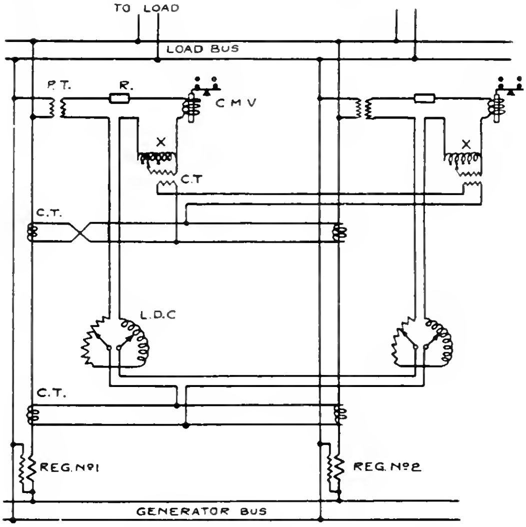

Fig. 25. Connections for Parallel Operation of Single-phase Regulators

In districts with high load densities, it is desirable to have a common polyphase secondary network. This will permit supplying power and lighting loads from the same mains similar to an Edison system. Some companies who have two-phase primary distribution are considering the two-phase five-wire system and the three-phase four-wire system shown in Fig. 26. The two-phase five-wire system can supply standard voltages for motors and lamps from the same mains. If the two-phase primaries are supplied from a three-phase source by T-connected transformers, there is a 6.7 per cent loss in transformer capacity. Two-phase motors may not be obtained as easily as three-phase motors. When used, a four-pole circuit breaker is required.

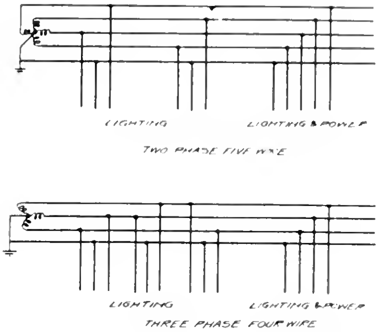

Fig. 26. Polyphase Secondary Networks

With a standard voltage to neutral to supply lighting load, in a three-phase four-wire network, the phase voltages will be below the standard motor voltage. With 125 volts to neutral the phase voltage is 216 volts. At the motor terminals the voltage may be as low as 205 or 200 volts. Standard motors are designed for emergency operation on 10 per cent above or below normal voltage. Where the motor load is a small part of the total load supplied by the network, auto-transformers may be installed to step up the motor voltage. This requires a separation of the lighting circuits from the motor circuits on the customer's premises. For the same voltage to neutral, this system requires approximately 6.5 per cent more copper than the two phase five-wire system. The primaries may be also three-phase four-wire which permits a higher transmission voltage using standard single-phase transformers where the existing system is three-wire. The Y-Y connection of the transformers with this system should cause no more telephone interference due to third harmonics than does the common practice of using single-phase transformers connected to three-phase or single-phase feeders. Mr. William C. L. Eglin in his article, "The Future Distribution System," in the *Electrical World*, December 17, 1923, gives the relative investment as 1.000 for the three-phase four-wire and 0.978 for the two-phase five-wire. The relative losses are given as 1.000 for the former and 1.045 for the latter.

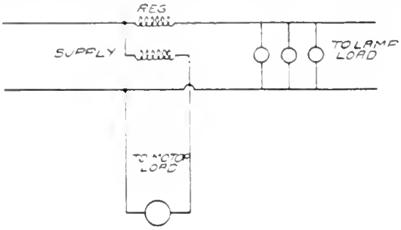

Fig. 27. Diagram of Connections of Voltage Stabilizer for Alternating-current Circuits

It will be necessary to limit the size of motor connected to the network and also avoid connecting motors which start and stop frequently, due to the low power-factor starting current. The starting current produces a drop in the transformers, mains and service lines which causes the lamps to flicker. Motors which are not large enough to cause a voltage variation on the mains may cause quite a drop in the service lines. To eliminate the instantaneous variation in voltage caused by starting the motor, a voltage stabilizer, shown in Fig. 27, may be used. This is essentially a reactive transformer having a primary through which the motor current flows, and a secondary which is connected in series with the lamp load and boosts the lamp voltage by an amount proportional to the voltage drop caused by the starting current of the motor. This of course requires the separation of the lighting and motor circuits. The stabilizer is provided with an adjustable air gap which permits adjusting the voltage induced in the coil connected in series with the lighting circuit within certain limits.

A-c. equipments for printing presses and elevators up to 540 ft. per minute have been developed and are giving satisfactory operation. For the present higher speed elevator equipments must be d-c. Rotary converters or motor-generator sets on customer's premises, or a skeleton d-c. system can be used to supply printing press and elevator loads where a-c. will not be feasible or permitted. Motors which cannot be supplied from the secondary network, due to their size and character of load, may be supplied from the primary mains. If the motor loads are dense enough, a separate network may be formed for power at a higher voltage than the lighting network.

The design of an a-c. secondary network requires an intensive economic study. Among the important factors which affect the successful and economical operation in addition to those already discussed are the size of conductor, spacing and size of transformers and the voltage drop in the mains. A paper entitled "Economic Study of Secondary Distribution" by Messrs. P. O. Reyneau and Howard P. Seelye, in the A.I.E.E. Transactions Part II, 1920, cover these points thoroughly. The same authors discuss the same factors, in addition to other factors of vital importance, in a book on "Economics of Electrical Distribution," published by the McGraw-Hill Company. The equations used will be mentioned here for the purpose of calling attention to their application. No attempt will be made to explain their derivation or all of the assumptions on which they are based.

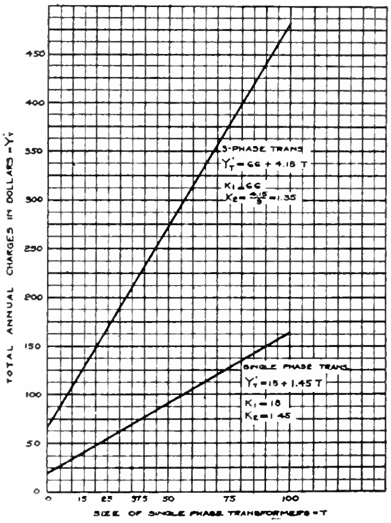

Fig. 28. Curves Showing the Annual Charges on Single-phase Transformers in Place, 15 to 100 Kv-a., 2300 volts Primary

The annual charges on transformers per 1000 ft. for overhead construction are expressed in an equation:

$$Y_L=\frac{1000}{S}(K_1+K_2\,T)=\frac{1000}{S}\left(K_1+K_2\frac{L_DS}{1000}\right) \tag{1}$$

The constants in this equation may be approximated by plotting the transformer size against the total annual charges of the transformer with protective equipment in place, as shown in Fig. 28. The annual charges per 1000 ft. on single-phase three-wire secondary mains in place are expressed in an equation:

$$Y_L = \frac{G_L}{100}(3000\,\omega\,C_{cu} + C_{SR})$$

$$+60.83\,S^2\left(\frac{L^2{}_D\,\rho t\,C_{e2}}{AE^2\,\mathrm{Cos}^2\,\Theta}\right) \qquad (2)$$

By adding equation (1) and (2) the total annual charges per 1000 ft. on transformer equipment and secondary mains are obtained.

$Y = Y_T + Y_L$

$$Y = \frac{1000}{S}\left(K_1 + K_2\frac{L_D S}{1000}\right) +$$

$$\frac{G_L}{100}(3000\,\omega\,C_{cu} + C_{SR}) + 60.83\,S^2\left(\frac{L^2{}_D\,\rho t\,C_{e2}}{AE^2\,Cos^2\,\Theta}\right) \qquad (3)$$

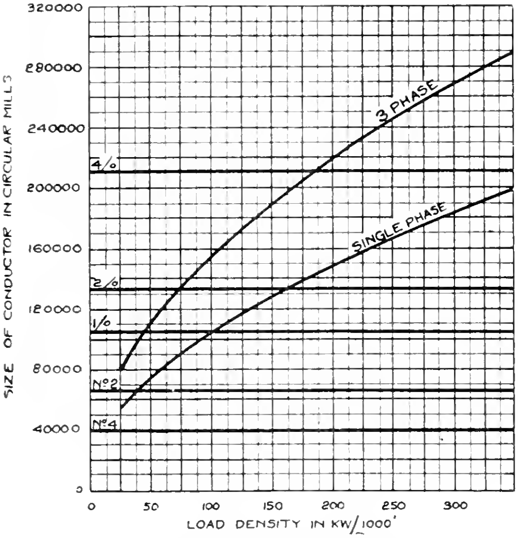

Fig. 29. Curves Showing the Most Economical Conductor Size

From this equation the most economical conductor, transformer size and spacing, and voltage drop may be determined. By making substitutions for certain of the symbols the equation may be differentiated with respect to the factor for which it is desired to determine the most economical condition. If Y is differentiated with respect to A and equated to zero an equation:

$$Acc = \frac{151}{(G_L K_4 C_{cu})^{3/4}}\left[\frac{K_1{}^2\,\rho t\,C_{e2}}{E^2\,Cos^2\,\Theta}\right]^{1/4} L_D{}^{1/2} \quad (4)$$

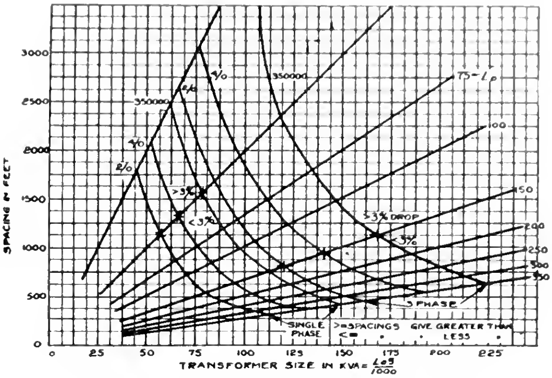

Fig. 30. Curves Showing the Most Economical Transformer Spacing

is obtained which gives the most economical size conductor. If Y is differentiated with respect to S and equated to zero an equation:

$$Sec = 2.02\left[\frac{K_1 E^2\,Cos^2\,\Theta}{\rho t\,C_{e2}}\right]^{1/3}\frac{A^{1/3}}{L_D{}^{2/3}} \qquad (5)$$

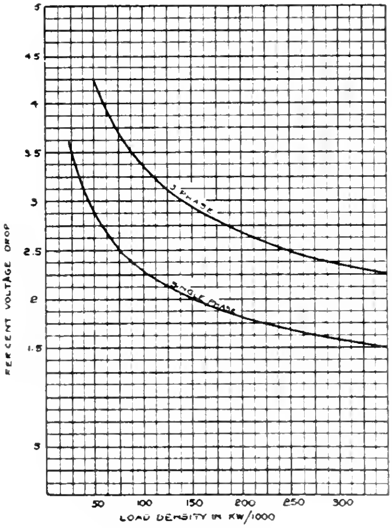

Fig. 31. Curves Showing the Most Economical Voltage Drop

is obtained which gives the most economical transformer spacing. Since the load is assumed uniformly distributed and the transformer just large enough to carry the load, the most economical transformer size may be obtained from the equation:

$$Tec = L_D\,\frac{Sec}{1000} \qquad (6)$$

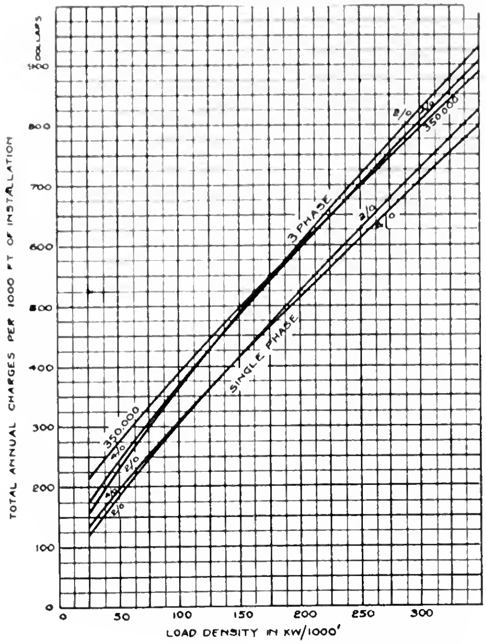

Fig. 32. Curves Showing the Comparative Economy of Various Wire Sizes in Secondary Installations with Transformers

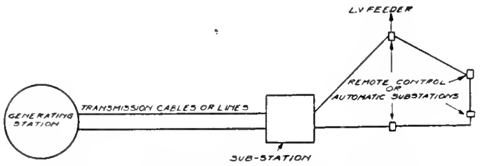

Fig. 33. Small Indoor or Outdoor Substations Supplied by Loop Feeders

The equation:

$$S = \frac{E}{17.32}\sqrt{\frac{AV}{BL_D}} \qquad (7)$$

gives the spacing for a voltage drop V. If this is substituted for S in equation (3) and then Y is differentiated with respect to V and equated to zero an equation:

$$Vec = 1223\left[\frac{Cos^2\,\theta}{E\,\rho t\,C_{e2}}\right]^{2/3}\frac{BK_1{}^{2/3}}{A^{1/3}L_D{}^{1/3}} \qquad (8)$$

is obtained which gives the most economical voltage drop.

These equations with some modifications were used to compare the economy of a three-phase four-wire network with a single-phase three-wire network. The curves of the equations are plotted in Figs. 29, 30, 31 and 32. It will be observed from Fig. 31 that the higher the load density the lower the most economical voltage drop. With a given load density and conductor size the transformer size and spacing may be determined from Fig. 30. If the conductor and transformer size are given the spacing may be determined. If the transformer size and spacing are given the conductor size may be determined. The curve in Fig. 32 shows the comparative economy with various wire sizes and also the difference between a three-phase four-wire network and a single-phase three-wire network, including only the secondary mains and transformer equipment. The equations and curves indicate ideal conditions which cannot be obtained in practice. They indicate the limitations and are a valuable guide. In making an actual layout several other types of curves based on the equations are very useful. An estimate was made considering local factors in a certain city and it was found that the three-phase four-wire worked out slightly more economical than the single-phase three-wire.

Messrs. Gear and Williams in their book on "Electrical Central Station Distributing Systems," published by D. Van Nostrand Company, give the equation:

$$Y = \frac{a}{R} + b\,C^2R + c\,C^2R$$

which gives the total annual charges of an electric circuit. By differentiating with respect to R and equating to zero the equation:

$$CR = \sqrt{\frac{a}{b+c}}$$

is obtained. Where it is customary to adopt either a standard feeder load or a standard

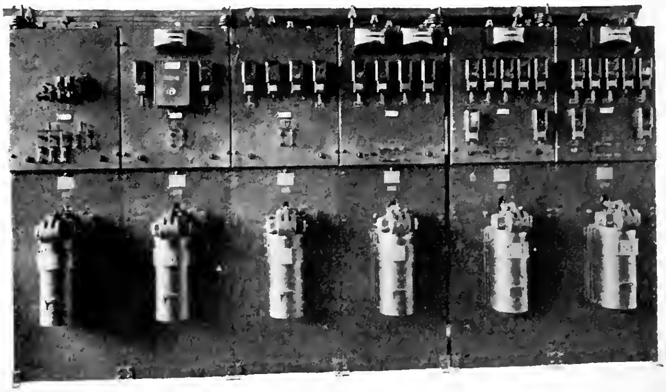

Fig. 34. Indoor Automatic Reclosing Equipment

Fig. 35. Automatic Reclosing Outdoor Equipment with Oil Switch

Fig. 36. Automatic Reclosing Equipment in Outdoor Switch House

wire size, the most economical size wire for maximum load may be obtained. A modification of Kelvin s law to determine wire size is given by Mr. Glen Smith in the *Electrical World*, December 17, 1921.

The advent of remote control and automatic reclosing equipments will permit methods of distribution which before, with some exceptions, were not permissible. Where new load centers are rapidly developing they may be supplied by small indoor or outdoor substations, instead of a large manually controlled substation, as shown in Fig. 33. The low voltage feeders may be remote controlled from the substations or equipped with automatic reclosing equipments illustrated in Figs. 34, 35 and 36. The breakers of the reclosing

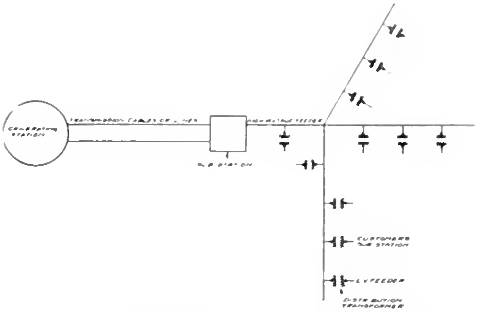

Fig. 37. High-voltage Feeders Supplying Distribution Transformers and Customers' Substations

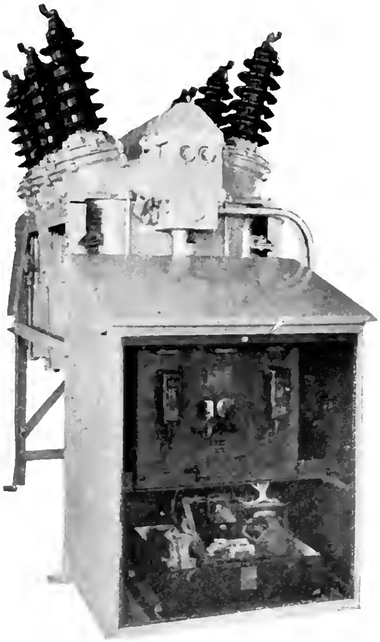

Fig. 38. Outdoor Automatic Reclosing Equipment for 33,000-volt Feeder

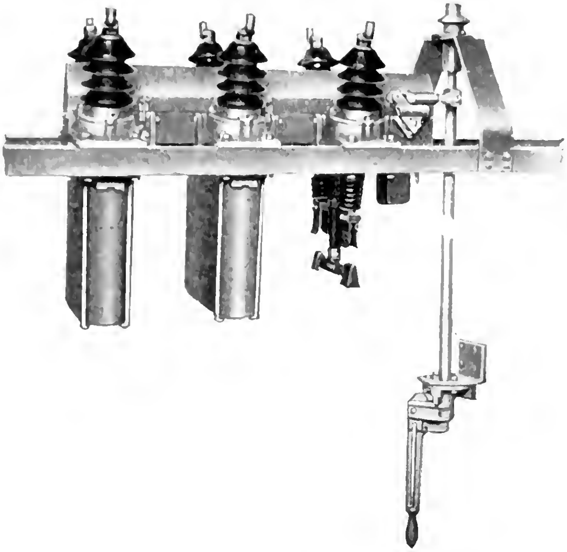

Fig. 39. Outdoor Oil Circuit Breaker, Triple-pole, Single-throw, 15,000 Volts, 400 Amp., Breaker Open, One Tank Removed

equipments are arranged to trip three times and reclose twice in case of a permanent fault. If the fault should clear itself before the preceding operations are completed, the equipment will remain in service as under normal conditions. If the fault does not clear, the breakers will lock out in the open position through a hand reset relay. After the fault is repaired the equipment is put back into service by resetting the relay. These equipments are also applicable to cases similar to Fig. 37. The branch feeders may be protected with automatic reclosing equipments or for circuits below 15,000 volts with the pole mounted breakers illustrated in Fig. 39 and 41. The feeders may be equipped with automatic reclosing equipments and the transformers with fuses or oil circuit breakers set so as to operate at a higher current and time setting than the feeder breakers. In some cases low voltage feeders to supply small power and light users may be located at the customer's substations. Where automatic or remote control is not desired outdoor switch houses with oil circuit breakers similar to Fig. 40 may be used. These are particularly useful at small outdoor substations tapped to a high voltage transmission line or feeder.

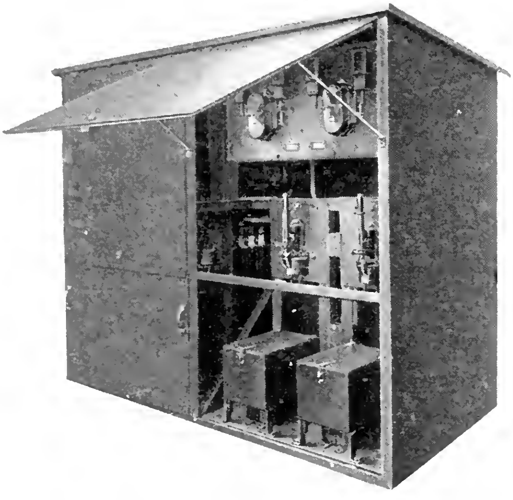

Fig. 40. Outdoor Switch House, Three-phase, Four-circuit, Showing Front and Doors Open on Two Circuits

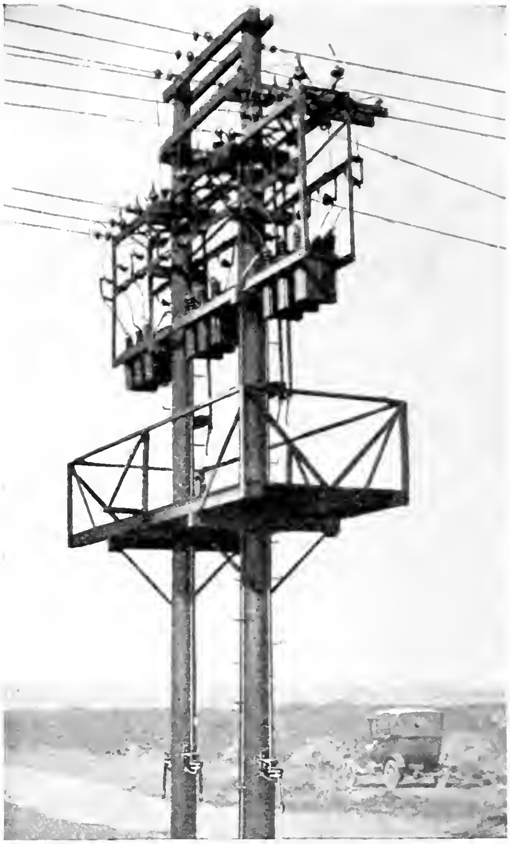

Fig. 41. Three Manually Operated Oil Circuit Breakers Installed on Transmission Line

Acknowledgment is made to Mr. C. G. Jeter and Mr. E. D. Treanor of Pittsfield, for information furnished on the network protector and auto-transformer scheme for balancing load on a-c. secondary networks.

Applying the Results of High-voltage Research to Practice

By F. W. Peek, Jr.

Pittsfield Works, General Electric Company

The value of research work in solving our "field problems" in high-voltage transmission is ably shown in this article. The testing laboratory where so many notable results have been accomplished is briefly described and the construction of a million-volt transmission line considered. The use of the insulation shield is shown in our illustrations.—Editor.

While it is probably true that research work should be carried on in a systematic way regardless of apparent immediate practical application, nevertheless the research worker will have a much broader aspect if the possibility of application is kept in mind. It is also true that practical application is never more apparent than in the laboratory demonstration. The pure physicist who looks with disfavor upon the consideration of practical application should remember that he would soon be without tools if the results of his work were not practically applied. When theory and practice disagree it generally means that theory is wrong in not including all of the variables. The most difficult part of a research is, in fact, the proper application of the result to practice.

It is the purpose of this paper to discuss the methods and apparatus used in high-voltage research.

In this connection, a brief description of the "High-voltage Engineering Laboratory" at the Pittsfield Works will probably be of interest.* This laboratory is equipped with the apparatus necessary to carry on the problems of pure and applied research as well as the more immediate developmental problems. The first essential of such a laboratory is plenty of free space. A single example will make this apparent. During a recent investigation sparks over eighteen feet in length were obtained. Fig. 1 gives a view of the "million-volt" corner of this laboratory. A good idea of the size is obtained by noting the visitors in the gallery observing the nine-foot, 60-cycle arc. Fig. 2 shows a view in the opposite direction. At the time this picture was taken a full size section of a 220 kv. transmission tower was erected in order to study the effect of the tower on the behavior of the insulator shield.

It is possible to make this whole laboratory dark in a few minutes. A smaller dark room is available for tests up to 300 kv. as shown in Fig. 5. The whole building is of substantial brick construction and kept at practically constant temperature inside.

A great variety of apparatus is available for use in both pure and practical researches.

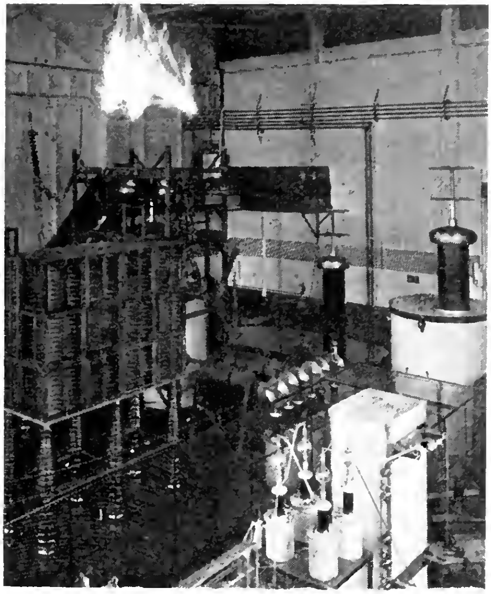

Fig. 1. Million-volt Corner of the High-voltage Engineering Laboratory Showing Lightning Generator and Million-volt Transformers

In fact, almost any condition that can occur in practice can be simulated. A partial list may be of interest and is as follows:

A million and a half volts single-phase; a million volts to ground and a million volts three-phase (root mean square) at commercial frequencies; damped and undamped high frequency oscillation; high voltage d-c.; arcing grounds; two million volts, lightning, etc. Apparatus is also available for studying the effects of such weather conditions as heat and cold, and rain and dew formation on insulators. Special measuring instruments

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* This laboratory was completed in July, 1914. At that early date a 750-kv. transformer was available.

are also available. As an example, spheres 100 cms. (40 inch) in diameter are necessary to measure the very high voltages.

Some investigations are started purely from theoretical reasoning and others from suggestions received in practice. Quite often a practical result is obtained from work started on a theoretical basis while the truth of a theory often is established from the work started from a practical suggestion.

Fig. 2. Section of Full-size 220-kv. Tower Erected in the Laboratory to Study the Effect of the Tower on the Behavior of the Insulator Shield

A short description of some specific investigations taken at random may give a better idea of how this work is carried out.

The lightning generator, shown in Fig. 1, will produce voltages of approximately two million. This is perhaps higher than lightning voltages that are usually induced on transmission lines. These voltages are of a known wave shape and duration. The wave front is under control and is very steep. In fact, it may be made so steep that the voltage starting at zero or line voltage may increase at the rate of 50 million million volts per second. The rate that the energy is dissipated in the arc is generally in the order of millions of horse power. The duration of such discharges is conveniently measured in micro seconds (one micro second = one millionth of a second).

The development of this impulse or lightning generator resulted from observations made on a transmission line in 1913. Some switch bushings with a 60 cycle arc-over voltage of about 100 kv. were "protected" by a low gap lightning arrester set to spark over at about 25 kv. 60 cycle. Lightning always sparked over the bushing. It took the horn such a long time to discharge that the rapidly increasing lightning voltage rose to over 100 kv. and discharged over the bushing which was of a design with very little time lag. Although the lag is generally less than a millionth of a second, a lightning voltage, increasing at the rate of millions of kilovolts per second, can become quite high in this time.

In order to study this phenomena an impulse or lightning generator was developed that gave a very high voltage, a wave shape under control and of definite value.[1] The phenomena observed in practice were repeated in the laboratory. The result was that spheres were added to the arrester gap and the discharge voltage was probably reduced to about one quarter. The difference between successful and unsuccessful operation here was a slight change in the electrodes. The sphere has very little lag because the field is practically uniform and the break occurs in the gaps everywhere simultaneously. With the needle or the horn the field is irregular and

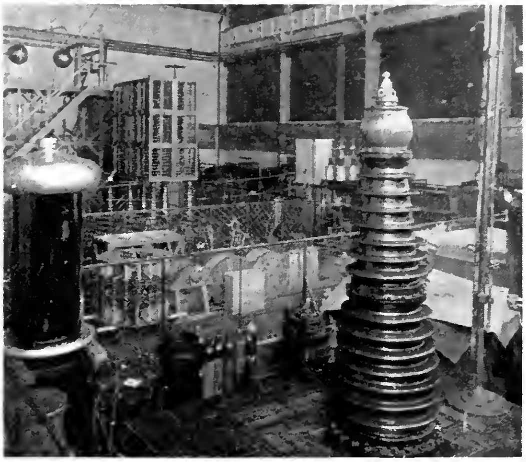

Fig. 3. Another corner of the High-voltage Engineering Laboratory

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[1] Peek, F. W., Jr., "The Effect of Transient Voltages on Dielectrics," Part I, Transactions A.I.E.E., 1915, Vol. 34, p. 1857; Part II, A.I.E.E., 1919, Vol. 38, p. 1137. "Lightning," GENERAL ELECTRIC REVIEW, July, 1916.

a sphere of corona must be formed before arc-over can occur. This takes time. The modern bushing on the other hand is designed to have a very high lightning spark-over voltage. In this investigation, much data of theoretical interest was obtained and the term "impulse ratio" added to our "engineering" vocabulary.

The original generator which was designed for 200 kv. has been added to from time to time as available exciting voltages have increased. Approximately two million volts is now available with a discharge rate of millions of kw.

In order to apply the laboratory results to practice it is necessary to know just what occurs in practice. This information is obtained by making measurements on actual lines. In one investigation the voltage, current and "frequency" of lightning induced on transmission lines were actually measured.

Other transient or "predatory" voltages that occur on transmission lines are surges, or highly damped oscillations, caused by arcing grounds or switching. Undamped oscillations have never been observed. Nor would these be expected since even if they were started they would soon be damped out by the losses.

The insulator shield shown in the tower in Fig. 2 is a development recently brought to a practical stage for 220-kv. transmission. Unlike the sphere lightning arrester gap this device was first started from the theoretical or mathematical end.[2] It is generally well known that, when an insulator string is not shielded, 25 to 30 per cent of the 60 cycle voltage appears across the units of the line end. This is obviously not desirable. With the shield, each unit takes its share of the voltage. The shield also prevents corona on the line conductor and the insulator units. Another very important use of the shield is to prevent the arc from cascading and the following dynamic destroying the string.

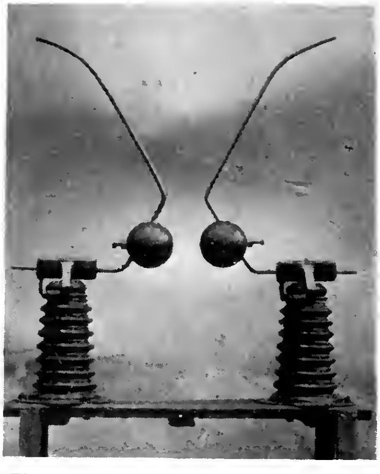

Fig. 4. Original Sphere Horn Arrester Gap

Fig. 5. Small Dark Room with Office Above. This dark room is equipped for tests up to 300 kv. to ground

The lightning investigation has been of great help in tying-in research with practice. The shield was designed so that lightning and such oscillations as appear on transmission lines cleared the string. The results are shown in Figs. 7, 8, and 9.* It will be noted that even during rain, lightning clears the insulators. Incidentally, Figs. 6 and 7 show by far the highest voltage and the greatest energy ever produced in a lightning stroke in the laboratory. Lightning voltages of such magnitude rarely occur on transmission lines, for it is very seldom that lightning sparks over a seven-unit string.

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[2] Ryan, Harris J. & Henline, "Unit Duties on Long Suspension Insulators," A.I.E.E., July, 1920.

Peek, F. W., Jr., "Electrical Characteristics of the Suspension Insulator," Part I, A.I.E.E., 1912. Page 907; Part II, A.I.E.E., 1920, Vol. 39, p. 1685; *Electrical World*, Feb., 1920.

* The author was ably assisted by Mr. W. L. Lloyd in obtaining these data.

The shield does not lower the lightning arc over voltage of the string. It would obviously be wrong to use a type of shield in practice because it gave a spectacular performance with radio frequency in the laboratory. There is continual danger of falling into error in this way.

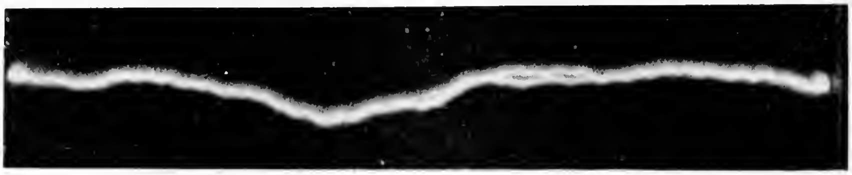

Fig. 6. A 1,500,000-volt Lightning Stroke between Points

Fig. 7. Spark-over of Shielded Insulator String; dry, 60 cycles

Fig. 8. Spark-over of Shielded Insulator String; single lightning stroke, 1,200,000 volts, dry

Fig. 9. Spark-over of Shielded Insulator String; single lightning stroke 1,200,000 volts, during heavy rain

Fig. 10. Spark-over of Non-Shielded Insulator String; single lightning stroke 1,200,000 volts, dry

Although it is probably not generally known, a similar shield is used most effectively in transformers. Under normal operation the windings assume their correct voltages by induction. At the instant a lightning stroke strikes a transformer, however, the high inductances act as open circuits to the steep wave front. The transient voltage distribution is controlled by the capacity of the windings. In other words, at this instant the transformer is, in effect, an insulator string. The shield causes equal voltage distribution and prevents oscillations.[3] This shield has proved most effective.

It is always well to make a model "set-up" of apparatus before practical application is made on an extensive scale because it is not always possible to foresee all of the variables that may enter into a combination. It is also a fact that some phenomena, unimportant in certain stages, may suddenly become of commanding importance, as, for instance, the corona when the loss jumps from zero to high values with a slight change above a critical voltage.

In the preliminary stages of the 220 kv. development, in addition to the insulator tests in a full size tower, a model three-phase line was operated at full voltage. The fact of principal interest that developed was the triple harmonic caused by corona.[4] A study was also made of the propagation of lightning along this model transmission line.

In the laboratory it is often necessary to improvise apparatus to get results in a hurry. In fact the first million volts were obtained (September 13, 1921) by putting two standard testing transformers in series. Only the addition of a bushing and other slight insulation changes were necessary to obtain over a million volts from these two ten-year-

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[3] Weed, J. Murray, "Prevention of Transients in Windings," A.I.E.E., Feb., 1919.

Blume, L. F. and Boyagian, A., "Abnormal Voltages in Transformers," A.I.E.E., Feb., 1919.

[4] Lewis, W. W., "Some Transmission Tests," A.I.E.E., June, 1921.

Peek, F. W., Jr., "Voltage and Current Harmonics Caused by Corona," A.I.E.E., 1921, Vol. XL, p. 1155.

old transformers.[5] The test was made hurriedly to see if existing laws of corona and spark-over held at the very high voltages. This was found to be so. The present permanent equipment, which can be seen in Fig. 1, was specially designed for the purpose of general laboratory use and has been adequately described.[6] There are, of course, many uses for a million volts in the laboratory from the standpoint of pure research. It may not be out of place to conclude this article with a discussion as to just what are the *possible* uses of a million volts in practical transmission.

The conductor would probably be about 6½ inches in diameter. If it is assumed that this is a hollow tube with copper equivalent to a one-inch diameter rod, it is possible to transmit three million kilowatts a thousand miles with about 12 per cent loss and a million volts at each end. If five-inch tubes were used there would be very little loss in fair weather but during a rainstorm the loss would be of the order of 1000 kw. per mile. An approximate idea of the size of a 1000-kv. tower compared with a 220-kv. tower is shown in Fig. 11

The striking fact that these figures bring out is the large amount of power necessary to make such a line economically desirable. They also emphasize the enormous size of the apparatus units necessary. If present practice were followed 1,000,000-kw. transformer units would be necessary. This would probably mean erecting in the field. The problem of size and transportation becomes greater than the problem of voltage.[7] However, it is only a little over ten years ago that the 200-kv. line was in a similar laboratory stage as the 1,000,000-volt line discussed above.

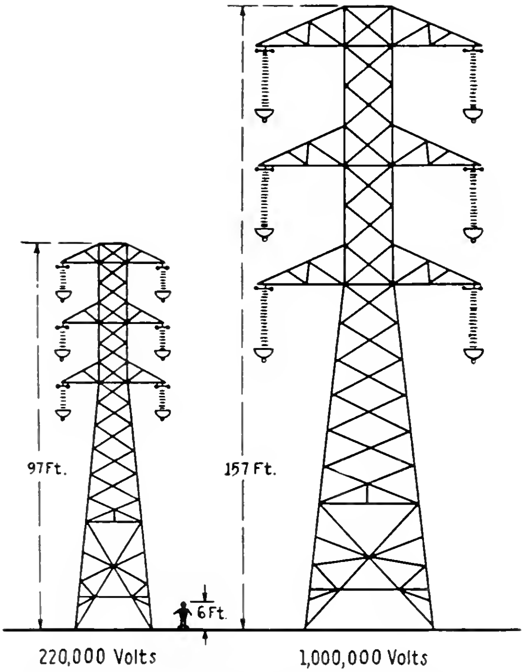

Fig. 11. Comparison of 1,000,000-volt and 220,000-volt Transmission Towers

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[5] Peek, F. W., Jr., "Tests at 1,000,000 Volts," *Electrical World*, Dec. 31, 1921.

[6] Hendricks, A. B., "A Million Volt Testing Set," A.I.E.E., Oct., 1922.

[7] Peek, F. W., Jr., "High Voltage Power Transmission," Proceedings American Society of Civil Engineers, November, 1922.

Resynchronizing Characteristics of Synchronous Motors

By O. E. Shirley

Alternating-current Engineering Department, General Electric Company

The resynchronizing of synchronous motors under heavy load is a new engineering accomplishment. Successful results were obtained only by redesigning certain features of the motor and by originating several new auxiliary devices. The author discusses factors for successful operation, torque characteristics and tests under operating conditions. He then shows the results of interruption in power supply and concludes his article with some remarks on general operating characteristics.—Editor.

The usual applications of synchronous motors have been for purposes where in case of failure of power supply the motor could be allowed to shut down, and then started up in the usual way after the return of the voltage to normal. Recently, however, there has been a tendency toward automatic operation, and more attention is also being paid to minimizing interruptions, so that a motor and control which will allow the motor to remain connected to the line, either directly or through a protective reactance, is very desirable. These motors may be used to great advantage where momentary interruption of output is allowable, but where it is essential that normal operation should be restored as quickly as possible.

There are two classes of service for which these motors have been used.

The first class is for motor-generator sets which are connected to an Edison direct-current system with storage battery reserve. The minimizing of the time of interruption of power supply is quite important, and a considerably smaller battery reserve will be allowable, if the motor-generator set will pick up the load immediately after the return of the main a-c. power.

The second class is for frequency converters which are operating singly or in parallel, but where there are no other generators operating in parallel with the generator units of the sets. The usual interruption of power is caused by a short circuit on the system supplying power to the motors of these sets, which will cause the voltage to drop to values ranging from zero to practically normal at the motor terminals. The motor voltage may be less than the breakout voltage corresponding to the excitation and load on the set, and if the duration of the voltage drop exceeds from $^1\!/_4$ to $^1\!/_2$ second with from one-half to normal load, the motor will usually drop out of step. When the trouble clears, the voltage almost immediately comes up to a value between 60 and 100 per cent normal, depending on the relative size of the motor and the system, and the line drop, and it is very desirable to have a motor that will pull into step without having to go through the usual starting procedure.

Factors for Successful Operation

The successful operation of a synchronous motor for resynchronizing after an interruption in power supply is dependent on two factors: the inherent design of the motor, and the functioning of the control equipment.

It is usually quite practicable to design the motor with sufficient torque at speeds close to synchronism to enable it to pull into step with a considerable percentage of load; but the current input at lower speeds may in some cases be objectionably high from the operating standpoint, as well as requiring considerable extra bracing of the coils to prevent distortion. It is, therefore, usually advisable to provide control equipment to change the connections of the motor (usually delta to Y); to throw over on a compensator; or to insert protective reactance in the circuit, when the speed drops below a certain predetermined value, depending on the design of the motor and operating conditions. The voltage of the power supply is quite likely to return after an interruption at a value somewhat lower than normal, and it is advisable to have a device for automatically reducing the load of the motor until it pulls in. This reduction in load may be accomplished, in the case of a motor-generator set or frequency converter, by inserting resistance in the field of the generator until the motor pulls in.

The torque of a synchronous motor, when operating at sub-synchronous speed, is considerably reduced by field excitation, and, therefore, some means should usually be provided for removing this field excitation. The torque near synchronism may be increased by the proper value of external resistance in the field, and the field circuit may be arranged so that the field discharge resistor is connected in when the excitation voltage is removed. This lends itself to simplicity of control, as the discharge of the field is taken by the discharge resistor without other complication of control. The removal of the excitation and the use of a resistor in the field circuit has the additional advantage in the case of interruption of power in that the current surge, when the voltage returns, is very much less than if the excitation is left on. Motors with direct-connected exciters are sometimes arranged so that the field is left connected across the exciter, and if the speed drops far enough, the exciter loses its voltage and consequently the excitation is removed from the motor field. This method of operation does not give nearly as good pull-in torque as closing the field on the discharge resistor, but is somewhat simpler in control, and may be used if the lower value of pull-in torque is all that is required. This connection, however, introduces the danger that the exciter may not drop far enough in speed to remove the excitation, and there will be a very high surge of current when the voltage returns, especially if the voltage returns at full value instantaneously, as would be the case if the switch were closed on the motor.

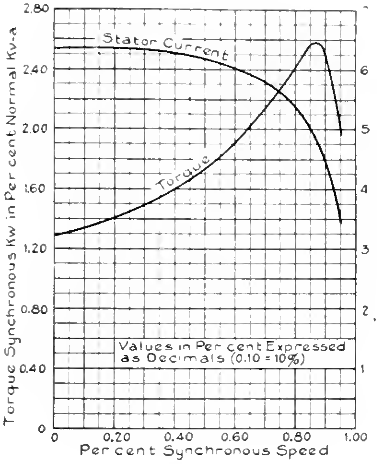

Fig. 1. Torque and Stator Current Curves of a 6000-kv-a. 25-cycle 11,000-volt 300-r.p.m. Synchronous Motor with Field Circuit Open

There are not yet much data available as to the relative values of torque at 95 per cent speed, which is approximately the speed from which the motor will pull in with field applied for these various methods of control; but the tests now available indicate the following values, based on the torque with the field open circuited as 100 per cent.

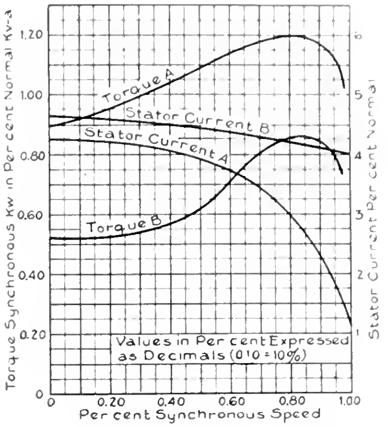

Fig. 2. Torque and Stator Current Curves of a 1600-kv-a. 60-cycle 6600-volt 720-r.p.m. Synchronous Motor

Curve *A*, Field circuit open; Curve *B*, Field circuit closed through exciter, with normal setting of main and exciter field rheostats

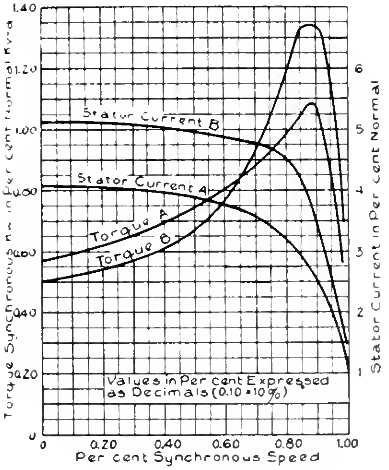

Fig. 3. Torque and Stator Current Curves of a 1400-kv-a. 60-cycle 13,800 6900-volt 720-r.p.m. Synchronous Motor

Curve *A*, Field circuit open; Curve *B*, Field circuit closed through resistor with 6.2 times resistance of field winding

With the field short circuited or, with various values of field current up to 80 per cent normal excitation = 70 per cent torque.

Field with discharge resistor = 120 per cent torque.

Torque Characteristic Curves

A number of torque curves of synchronous motors of the type for high pull-in torque have been taken by the "Acceleration"* method, and a few representative cases are given. These curves were taken at reduced voltage and corrected to full voltage, assuming the torque varies directly as the square of the voltage, and the starting current varies directly as the voltage.

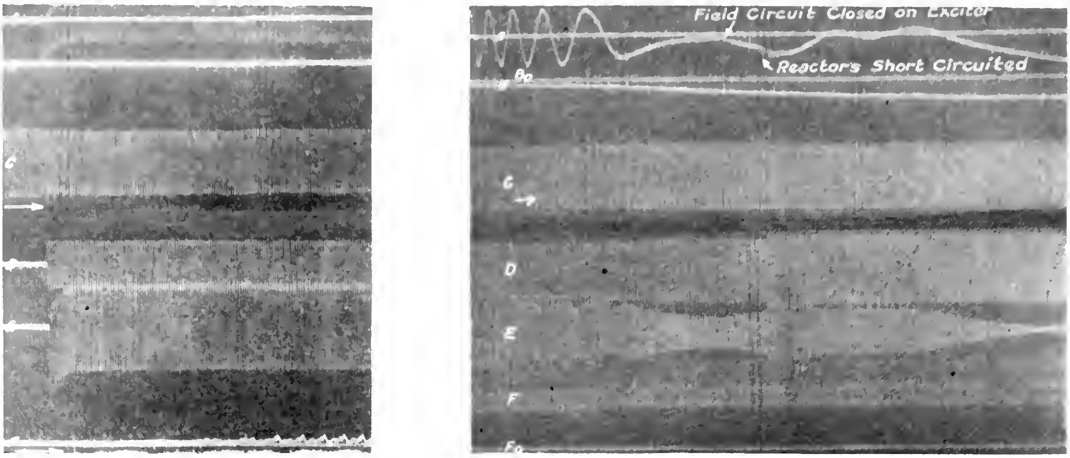

Fig. 4. Oscillograms of Starting Test of a 2500-kv-a. 60-cycle 13,200-volt Synchronous Motor, Direct Connected to an 1875-kw. 250-volt Direct-current Generator. Field closed through resistor with 6.1 times resistance of field winding. Starting from line with 10 per cent series reactors

(*Left*) Initial start. (*Right*) Synchronizing, showing closing of field circuit on exciter, and short circuiting of reactors

Curve *A*, Motor field current; *B*, D-c. generator terminal voltage; *C*, A-c. line voltage; *D*, A-c. motor voltage; *E*, A-c. line current (also motor current); and *F*, Speed of set.

Fig. 1 is the curve for a 6000-kv-a., 25-cycle motor with field circuit open. This curve shows the usual characteristics of the low resistance amortisseur winding; comparatively low starting torque, high peak in the torque curve near synchronism, and quite high starting current with full voltage.

Fig. 2 for a 1600-kv-a., 60-cycle motor gives a comparison of the performance with open field and with field closed on the exciter which was set for normal operating conditions. The curve for the latter condition is not exactly correct near synchronism, as the torque, due to the field excitation, does not vary as assumed above; but the curve is very nearly correct through most of the range. It may be seen that the torque is quite materially reduced with the field connected across the exciter, and also that the current is increased. The torque efficiency, that is, the torque in synchronous kw. divided by the kv-a. input, is very much less with the exciter connected in than with the field open.

Fig. 3 for a 1400-kv-a., 60-cycle motor shows very clearly the increase in torque near synchronism, due to the use of a proper resistor in the field circuit. The "Acceleration" method of testing is not absolutely accurate in this case as the motor accelerates very quickly near synchronism, which introduces errors in the torque curve. A number of curves were taken for various values of resistance in the field, and they were very consistent in indicating the peak in the curves so that there is no question that the use of a resistor in the field materially increases the torque near synchronism. The curve given in Fig. 3 is the average curve as indicated by several tests.

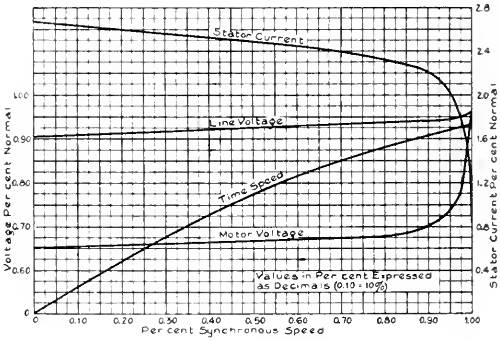

Fig. 5. Starting Characteristics of Synchronous Motor from Oscillograms, parts of which are shown in Fig. 4

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*"Synchronous Motor Starting Torque Characteristics," by O. E. Shirley, GENERAL ELECTRIC REVIEW, October, 1921.

Tests Under Operating Conditions

The behavior under actual operating conditions of a motor-generator set with motor designed for resynchronizing was tested in co-operation with the Union Gas & Electric Company at Cincinnati, Ohio, and several oscillograms taken during these tests are given to show the results secured.

The motor-generator set consists of an 1875-kw., 250-volt, d-c. generator, direct connected to a 2500-kv-a., 0.85-p-f., 13,200-volt, 3-phase, 60-cycle, synchronous motor with a 28-kw., 125-volt direct-connected exciter.

This set has a control which starts it up when the line is energized from the main generating station. When the set reaches a speed corresponding to about 95 per cent of the system speed, a slip relay actuates the control, closing the motor field circuit across the armature of the exciter, and this in turn operates the closing mechanism of

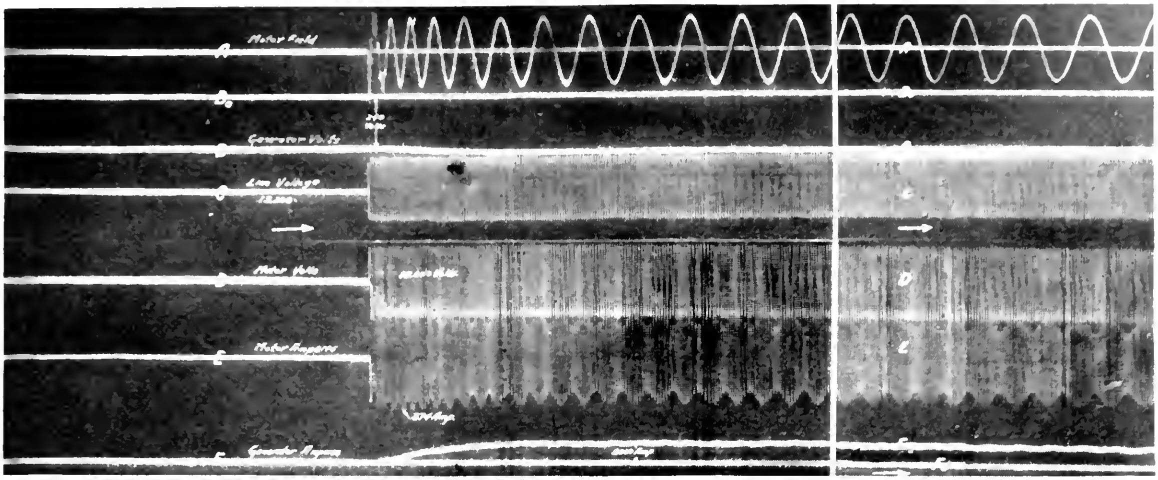

Fig. 6a. Oscillograms of Resynchronizing Test from 84 Per Cent Speed. 2500-kv-a. 60-cycle 13,200-volt synchronous motor direct connected to 1875-kw. 250-volt direct-current generator. Field closed through resistor with 6.1 times resistance of field winding. Motor connected to line through 10 per cent series reactors

Curve *A*, Motor field current; *B*, D-c. generator terminal voltage; *C*, A-c. line voltage; *D*, A-c. motor voltage; *E*, A-c. line current (also motor current); and *F*, D-c. generator line current

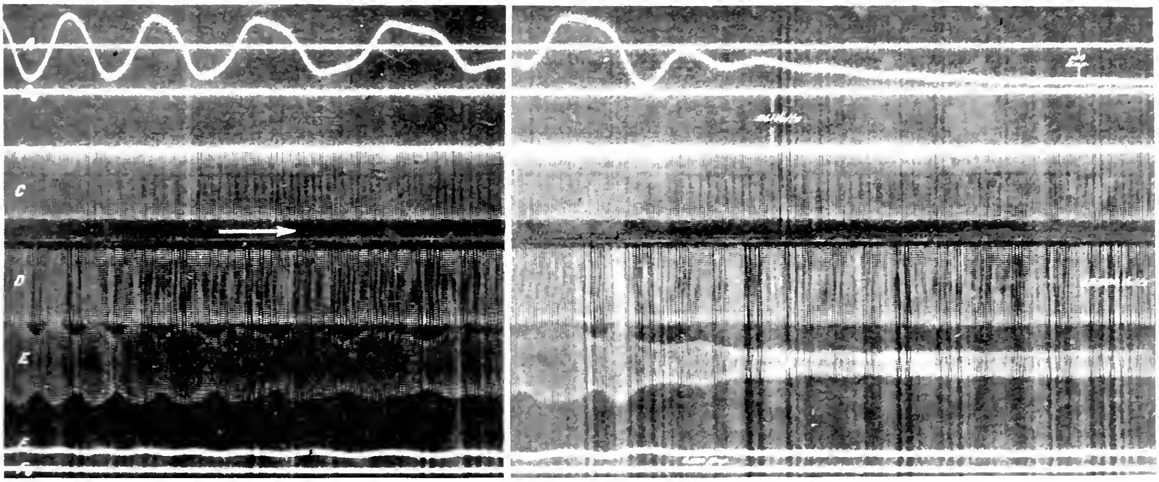

Fig. 6b. Continuation of Oscillograms in Fig. 6a

the reactor short circuiting switches. The d-c. generator is automatically paralleled with the d-c. system and picks up its load without attention of an operator.

A complete description of this substation is to be given in the N.E.L.A. report for 1922, by the Direct-current Substation Committee.

Starting Test

Fig. 4 is an oscillogram, showing the initial and synchronizing period of a regular starting test. The motor is started by throwing normal voltage on directly through protective reactors, having approximately 10 per cent reactance. The values of line voltage, motor voltage, stator current (also line current) and time, are plotted against synchronous speed. Refer to Fig. 5 for these curves.

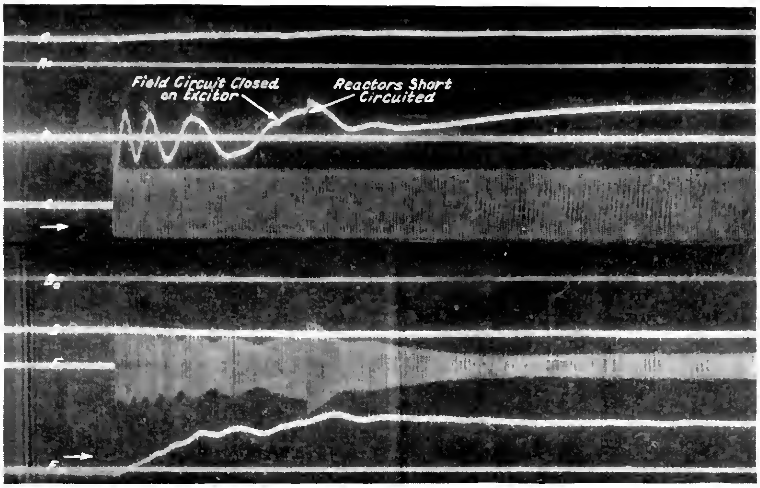

Fig. 7. Oscillograms of Resynchronizing Test from 90 Per Cent Speed. 2500-kv-a. 60-cycle 13,200-volt synchronous motor direct connected to 1875-kw. 250-volt direct-current generator. Field closed through resistor with 6.1 times resistance of field winding. Motor connected to line through 10 per cent series reactors

Curve *A*, Exciter voltage; *B*, Motor field current; *C*, A-c. line voltage; *D*, D-c. generator terminal voltage; *E*, A-c. line current (also motor current); and *F*, D-c. line current

A similar starting test, including the complete cycle, was also taken, and the set came up to speed, the exciter built up, the motor field was applied, the reactor short circuited, and the motor synchronized in 18 seconds. The d-c. generator built up to normal voltage and was connected to the d-c. bus about 10 seconds later. The generator load was then adjusted automatically to its proper value for holding voltage at the center of distribution. This load adjustment was completed in 5 seconds after the generator was connected to the bus. This gives a time of approximately 33 seconds after energizing the a-c. lines for the set to be operating at its required output.

Resynchronizing Tests

These tests were made by operating the set at loads between 60 and 100 per cent and opening the a-c. main lines. The set then dropped to between 90 and 93 per cent speed with the d-c. machine operating as a motor. The speed was further reduced to a value of from 75 to 90 per cent by cutting out the resistance in a temporary rheostat in the field of the d-c. generator. The permanent rheostat is arranged to begin cutting in resistance as soon as the power returns, which reduces the load until the motor synchronizes, after which the rheostat adjusts the field to hold the proper value of load. This reduction in field enables the set to synchronize under practically any conditions of initial load or a-c. power supply.

Fig. 6 is an oscillogram of a test resynchronizing from 84 per cent speed. The generator load rises to about 110 per cent, after which it is reduced to 84 per cent at the time the motor pulls in. The motor was in step with the field on and reactor short circuited in approximately 10 seconds after the return of the a-c. voltage. The line current to pull in was approximately 2½ times the normal rated current of the motor.

Fig. 7 shows a similar test resynchronizing from 90 per cent speed. The motor came into step very quickly in this case with the d-c. load rising to 76 per cent when the motor reached synchronous speed. The set was up to synchronous speed with field applied and reactor short circuited in about 2.7 seconds after return of the a-c. voltage. The maximum peak value of current was about 2.7 times the maximum value of the normal current wave.

Interruption of Power Supply

The tests described above were more severe than actual operating conditions, as the speed of the set was reduced considerably below its usual value under normal operation.

A test was made operating at normal load, opening the power supply for a few seconds, and then reclosing the a-c. switch. Fig. 8 is an oscillogram of this test. The power was off 3.8 seconds during which time the speed dropped to about 90 per cent, the motor field opened on to the discharge resistor and the reactor short circuiting switches opened. The set came up to the speed which operated the slip relay, and the motor field closed 2.6 seconds after the return of the a-c. voltage; the reactor was short circuited about ¼ second later. The d-c. generator rheostat then started to adjust the load and in 7 seconds the load was back to normal. The total time from the return of the a-c. voltage until the set was in normal operation was slightly under 10 seconds.

GENERAL OPERATING CHARACTERISTICS

There are a number of different designs of motors for resynchronizing service. The three usual ones may be classified as follows:

1. Standard stator windings with low reactance amortisseur winding.
2. Special stator winding for Y connection, when starting, and delta connection for running, with low reactance amortisseur winding.
3. Standard stator winding with high reactance amortisseur winding.

These motors will, of course, all have low resistance amortisseur windings, and the stator reactance is not subject to much change, as it depends principally on the voltage and design characteristics of the motor, which cannot be easily modified.

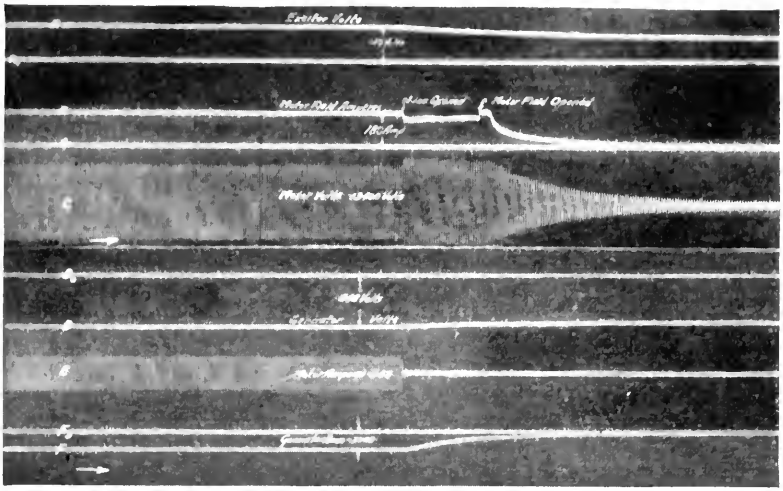

Fig. 8a. Oscillograms of Interruption of Power Supply and Resynchronizing Test. 2500-kv-a. 60-cycle 13,200-volt synchronous motor direct connected to 1875-kw. 250-volt direct-current generator. Field closed through resistor with 6.1 times resistance of field winding. Motor connected to line through 10 per cent series reactors

Curve *A*, Exciter voltage; *B*, Motor field current; *C*, A-c. motor voltage; *D*, D-c. generator terminal voltage; *E*, A-c. line current (also motor current); and *F*, D-c. line current

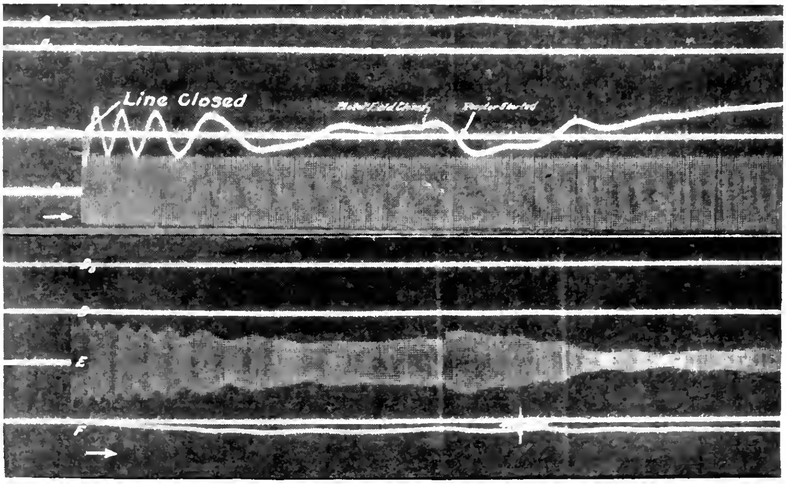

Fig. 8b. Continuation of Oscillograms in Fig. 8a

Motors classed as No. 1 are used for service when the speed will not drop below approximately 90 per cent, as in the case of motor-generator sets with storage battery reserve on the d-c. system. These motors may be started by reduced voltage from compensators. This design will give the best torque efficiency (starting torque in synchronous kw. divided by kv-a. input), and consequently the most desirable starting characteristics. It should be noted that a low resistance amortisseur winding, which is necessary for a resynchronizing motor, does not have nearly as good torque efficiency at starting as a motor with the usual high resistance winding designed for starting duty only, and consequently the kv-a. input for starting on the former class of machines is materially higher than for the latter class.

The use of a compensator may be eliminated for motors of class No. 2, and this class usually gives very satisfactory operation. The low resistance amortisseur winding gives quite low initial starting torque, and it is, therefore, usually necessary to design for low rotor reactance to insure starting on the Y connection. The control for this type of motor may be arranged to change over from Y to delta at a speed from 80 to 95 per cent, and also to change back in case the speed drops down to 5 per cent less than the value at which the change-over was made for increasing speed.

Motors of class No. 3 may be used when the motor is rather small in comparison with the system, and the higher starting current is not objectionable. Simplicity of control may be obtained by starting directly from the line through reactors which are short circuited when the motor comes up to from 80 to 95 per cent speed. The motor for this service being designed for higher reactance in the rotor, does not take as high initial starting current as motors of class No. 1, although the pull-in torque is slightly less than for the latter type.

Referring to Fig. 5 it is evident that the stator current is fairly constant as the motor comes up to speed, and does not begin to fall off materially until about 90 per cent speed is reached. It is, therefore, essential that the connection should not be changed from Y to delta until the motor is very nearly up to speed or there will be a considerably greater rush of current when the change-over is made than was obtained for the initial starting period.

The value of torque at which the motor can be pulled in is usually determined by the allowable current input that may be taken from the line. The 25-cycle motor, for which curves are given in Fig. 1, would pull in at nearly two times normal torque with full voltage applied, but the current required would vary from five times normal at 85 per cent speed down to 3½ times normal at 95 per cent speed. This current would be excessive, and a change of connections or the use of reactors would be desirable. The 60-cycle motor, Fig. 2, would take less than 3 times normal current from 85 per cent speed up, but the pull-in torque is only about 85 per cent normal. However, there will usually be quite a considerable line drop for these values of current, and, therefore, the motor may remain connected to the line after disturbances of one or two seconds duration without taking an excessive amount of current to pull back into step. Protective reactors, that may be inserted in the circuit in case the speed falls below a certain value, may sometimes be necessary if the motor is connected to buses close to large generating apparatus. The torque at which the motor will pull in successfully under ordinary operation will be from 40 to 100 per cent of normal, and it is usually not necessary to go above these values.

Reference to the torque curve *B*, Fig. 3, shows that the maximum peak of the torque curve is rather sharp and close to synchronism. In case the load comes up too quickly during the synchronizing period, or the voltage is low, it may sometimes happen that the load exceeds the peak of the curve, and then the motor behaves exactly like an overloaded induction motor and drops down in speed to a point where the slope of the curve between load and speed is greater than that of the torque curve of the motor. A motor-generator set with self-excited d-c. generator and straight resistance load not operating in parallel with other generators will drop down in speed to approximately 70 per cent of synchronism.

The application of resynchronizing motors to frequency converters has not been as widely extended as it should be, as with these motors and proper control it should be possible to maintain operation on the generators with only a short time of interruption in many cases where there is now a complete shut-down on the system. The usual short circuit disturbance is just about sufficient to drop the machines out of step, but the speed does not have time to decrease very far before the short circuit is cleared and the voltage returns on the motor lines. The use of a resynchronizing motor, and a reduction in load by automatic decrease of generator excitation until the set is in synchronism, should enable these machines to recover the load within a few seconds after the return of voltage on the motor lines.

Status of 220,000-volt Transmission

By G. F. Brown

Lighting Engineering Department, General Electric Company

The importance of an increase in transmission voltage, brought to commercial practice, is apparent when we realize the new fields of development it opens up. Our article describes the present status of 220,000-volt transmission giving a list of the installations now made and being made. The author discusses the apparatus, the use of lightning arresters and line insulation and then gives some notes on corona, line charging and regulation.—Editor.

For more than ten years there has been no substantial increase in the maximum voltage of power transmission. But the problems of transmitting at greatly increased voltage have received a great deal of attention in the last half of this period.

During the present summer it is expected that California will break another record, and the transmission of power at 220,000 volts will become an accomplished fact. Successful operation at this voltage will doubtless give impetus to other large projects, now under consideration, for which such a transmission voltage is essential.

The first extensive studies of 220,000-volt transmission were published in 1919.* The major power companies of California at this time were also studying the problem, being faced with the early necessity of transmitting very large blocks of power over distances of more than 200 miles. Their requirements were apparently outside the economic field of existing transmission voltages, on account of the excessive number of circuits required and the consequent high investment per kw. for transmission.

A capacity of 100,000 to 150,000 kw. per circuit fitted in well with their development programs, and was about double the circuit capacity with existing voltages. For these loads a transmission voltage of the order of 200,000 volts was required, and 220,000 was selected as the nearest voltage corresponding to the established practices of standardization.

It was felt that the problems of construction and operation at this voltage were not too far outside past experience. The manufacturers were prepared to build apparatus for this voltage on a commercial basis.

Estimates of cost showed that the investment for transmission would be 30 to 50 per cent below that required if the existing voltages were retained.

Having decided upon 220,000-volt transmission the power companies of California moved rapidly. Extensive investigations were undertaken by Mr. F. G. Baum† for the Pacific Gas & Electric Company. The Southern California Edison Company assigned Mr. R. J. C. Wood‡ and Mr. H. Michener to the investigation of their problems. Orders were placed for 220,000-volt apparatus as follows:

Southern California Edison Company

Date	Station	220,000-volt Apparatus
June, 1920...	Big Creek No. 8	Transformers and Circuit Breakers.
March, 1922.	Big Creek No. 3	Transformers and Circuit Breakers.
March, 1922.	Laguna Bell....	Transformers and Circuit Breakers.
March, 1922.	Existing Stations	Auto-transformers.

Pacific Gas and Electric Company

Sept., 1920 ..	Pit River No. 1.	Transformers .....
Jan., 1921...	Vaca Substation.	Transformers .....
July, 1921...	Pit No. 1 and Vaca Sub.....	Oil Circuit Breakers

The total transforming capacity installed at present, for 220,000-volt operation, is:

Pacific Gas & Electric Company, 200,000 kv-a.

Southern California Edison Co., 523,500 kv-a.

These figures include both step-up and step-down units, but do not include spare capacity. In addition there are 36 oil circuit breakers on these 220,000-volt circuits.

Fig. 1 shows Big Creek No. 8 Station—the first 220,000-volt hydro-electric station, and Fig. 2 shows the Vaca Substation—the first substation constructed for 220,000-volt operation.

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* "Problems of 220-kv. Transmission," by A. E. Silver, Transactions A.I.E.E., Vol. 38 (1919), p. 1037.

† "Voltage Regulation and Insulation for Large Power Long Distance Transmission Systems," by F. G. Baum, Transactions A.I.E.E., Vol. 40 (1921), p. 1017.

‡ "220-kv. Transmission," by R. J. C. Wood, Journal A.I.E.E., July, 1922, p. 471.

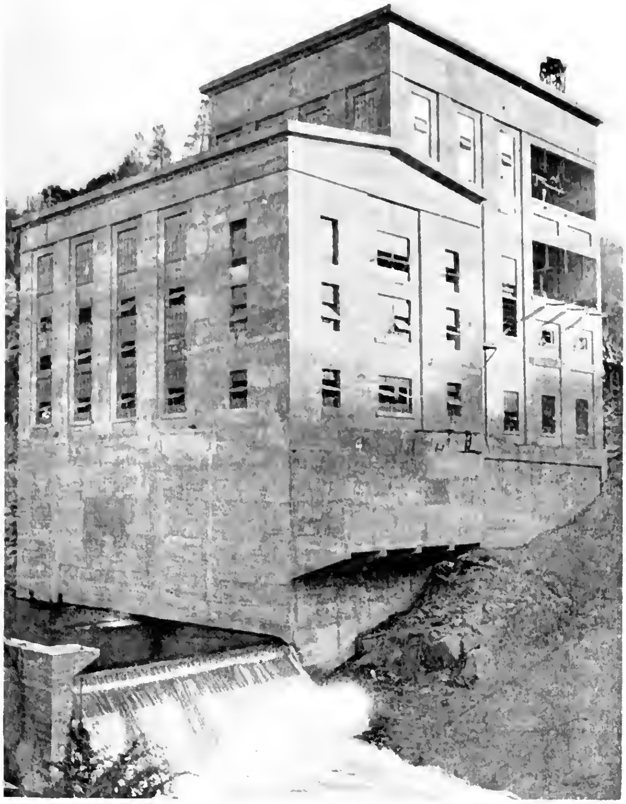

Fig. 1. Big Creek No. 8 Generating Station of the Southern California Edison Company

PROBLEMS OF 220,000-VOLT TRANSMISSION

Apparatus

The General Electric Company had been for some time prior to this engaged in a study of the design of apparatus for 220,000-volt service.

In the design of power transformers it was found that it would be very desirable to change the then existing practice of building transformers good for ungrounded operation. While it is entirely practicable to extend this practice to 220,000 volts, such designs were very expensive in comparison with similar transformers designed for permanently grounded operation. This reduction in cost is of the order of 35 per cent and is entirely due to the elimination of the heavy insulation at the ends of the windings and the consequent saving in space. No reduction is made in the turn and coil insulation, the insulation of buffer coils and coils throughout the stack being to the same specifications as that used for transformers designed for ungrounded operation.

In all of the transformers built by the General Electric Company for this service, the high-tension lead is brought to the middle of the coil stacks and progresses both ways through the winding to ground. This is shown diagrammatically in Fig. 16, page 346, and physically in Fig. 14, page 345. This idea of having the high-voltage terminal in the center of the stack was first put forward by Mr. W. J. Wooldridge of the General Electric Company in 1906 and patent was issued the succeeding year.

Fig. 14, page 345, shows the core and coils of the 20,000-kv-a. 220,000/72,000-volt transformers for the Laguna Bell substation of the Southern California Edison Company. Fig. 15, page 345, is of the complete transformer. There are seven of these units

Fig. 2. Vaca Substation of the Pacific Gas & Electric Company

installed, two banks of three, and one spare, each bank having an output of 60,000 kw. Fig. 3 shows the seven auto-transformers at the Vaca Substation of the Pacific Gas and Electric Company; these are also arranged in two banks and a spare; stepping down from 200,000 to 110,000 volts; output per bank is 50,000 kw. Fig. 4 shows the bank of 220,000-volt transformers installed in Big Creek No. 8 Power Station of the Southern California Edison Company. The capacity of this bank is 25,000 kv-a.

The oil circuit breakers, except as to size, insulation and clearance, are similar to the latest design for lower voltages. It does not appear that the interrupting duty on these breakers for some time to come will exceed that which many breakers are doing at lower voltages on the more concentrated systems in the East.

The oil circuit breakers supplied by the General Electric Company are of the explosion chamber type. Fig. 5 is the completely assembled breaker. Fig. 6 is a view of the cover with bushings, explosion chambers and insulation and separator mounted.

Lightning Arresters

No lightning arresters have been installed, neither has extra insulation been employed on the apparatus, as advocated by some engineers. Some engineers seem to have reached the conclusions that an operating voltage of 220,000 is of the order of induced lightning disturbance; that arresters are of little use in case of direct stroke; and that the solidly grounded neutral at all points reduces surges due to switching. Operating experience should yield useful information with due allowance for climatic and geographical conditions.

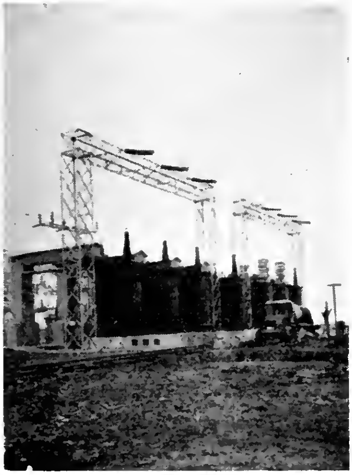

Fig. 3. Seven 200,000-volt Auto-transformers at the Vaca Substation of the Pacific Gas & Electric Company

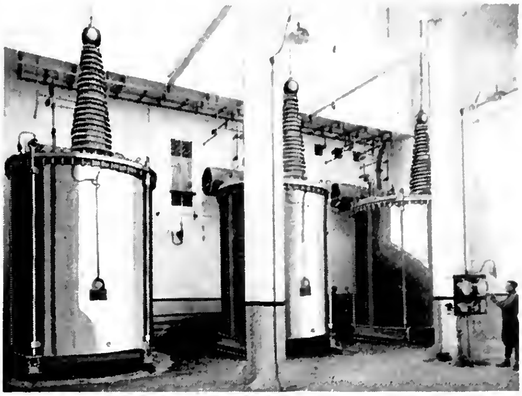

Fig. 4. Three 8333-kv-a. 220,000-volt Transformers Installed in Big Creek No. 8 Hydro-electric Station

Line Insulation

At the outset it was known that, due to uneven distribution of voltage over long strings of insulators, the unit next the line carried about 30 per cent of the total stress, and that this percentage was practically constant for strings of any number of units above five. Increasing the number of units would not lessen the duty on the insulator next the line, which at 220,000 volts was beyond that set by good practice.

Professor Harris J. Ryan* and F. W. Peek, Jr.,† pointed out several ways of correcting this uneven distribution, and lowering the duty on the line unit. Of the means suggested the two most promising were

a. Grading of insulators by use of units of different size at the line end.
b. Use of static shields.

The Pacific Gas & Electric Company have solved the problem along the lines of the first named method (see Figs. 7 and 8) while the Southern California Edison Company are using shield rings on strings of standard 10-inch units throughout (see Figs. 9 and 10). Extensive studies have also been made of the shield-

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*"Unit Voltage Duties in Long Suspension Insulators," by Harris J. Ryan and Henry H. Henline, Transactions A.I.E.E., Vol. 39 (1920), p. 1669.

†"Electrical Characteristics of the Suspension Insulator," by F. W. Peek, Jr., Transactions A.I.E.E., Vol. 39 (1920), p. 1685.

ing effects of the towers and location of shields for the purpose of minimizing the cascading of arcs over insulator strings at times of flashovers.

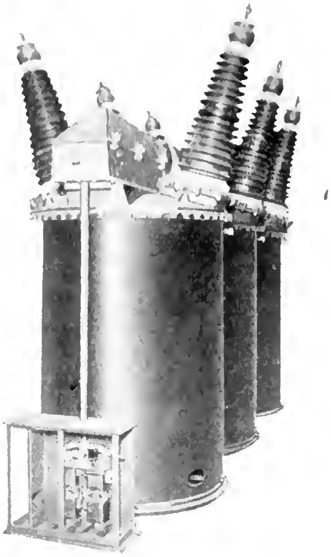

Fig. 5. Complete Oil Circuit Breaker, One of Eight that will Handle the 220,000-volt Circuits at the Laguna Bell Substation of the Southern California Edison Company

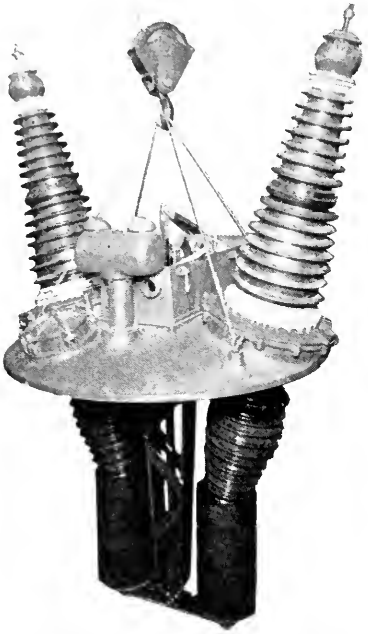

Fig. 6. Single Unit Oil Circuit Breaker Removed from Tank. These breakers are installed at the Laguna Bell Substation

Corona

Extensive field tests were conducted by the Southern California Edison Company on a 27-mile section of the line with voltages up to 280,000. The results are in accord with Peek's formula. Complete calculation for the Big Creek lines show negligible corona loss; none below 4000 ft. altitude. Under most extreme

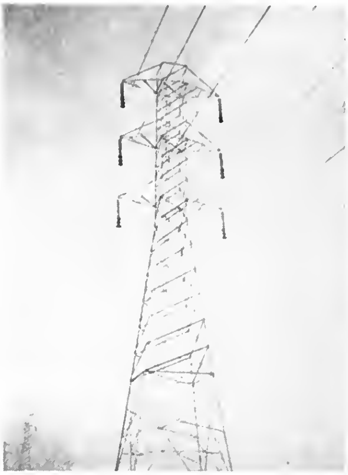

Fig. 7. Straight Line Tower on the 220,000-volt Pit River Line of the Pacific Gas & Electric Company

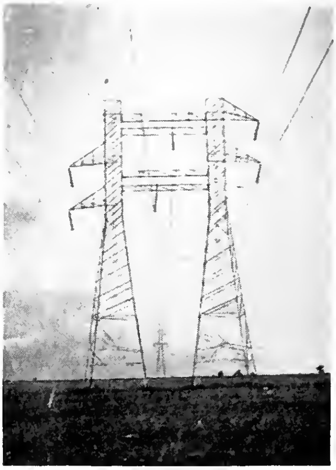

Fig. 8. Transposition Structure of the 220,000-volt Pit River Line of the Pacific Gas & Electric Company

assumptions as to storm conditions the corona loss is about 2 per cent.

Line Charging

In the matter of line charging it has been necessary to abandon past practice of building each generator large enough to pick up and control an unloaded circuit. Each of these California systems will require 40,000 to 50,000 kv-a. to charge a single circuit. It would require a 60,000 to 70,000 kv-a. generator of normal design to do this under normal operating conditions and still retain control of the voltage. This is about twice the size that other conditions have heretofore dictated for these developments.

Regulation

Synchronous condensers are installed at the receiving ends of these lines, in sufficient amount to maintain constant voltage from no load to full load.

Existing Plant and Equipment

The problem of raising existing stations on the Big Creek system from 150,000 to 220,000 volts has been solved by installing at each of these stations two banks of auto-transformers; one bank in each circuit. These banks are installed as an integral part of the line without switching equipment of any kind. Each bank is good for the entire output of the station; that is, under normal conditions they will operate at half load, which is the point of maximum efficiency. This plan showed the lowest cost, and high efficiency. It has the very decided advantages of simplicity and full use of existing equipment without change.

These projects have had the closest attention of all concerned, and operation will be begun with assurance that everything physically possible, that could contribute to their success, has been done.

Fig. 9. Anchor Tower on 220,000-volt Big Creek Line of the Southern California Edison Company

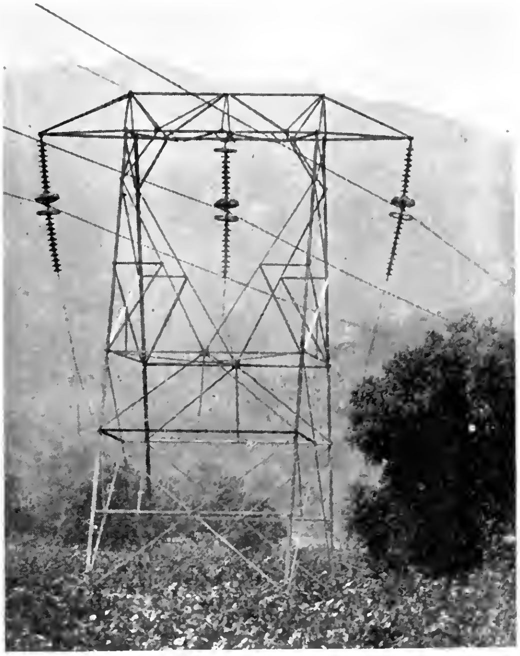

Fig. 10. Tie-down Tower on 220,000-volt Big Creek Line

Carrier Current Communication Over High-voltage Transmission Lines

By E. Austin

Radio Engineering Department, General Electric Company

Carrier current telephony is sort of a first cousin to wireless communication. It is likely to find extensive application on all large power systems and in the public utility field, and as there has been little publication on the subject, we believe the author's comprehensive and practical treatment will be appreciated.—Editor.

When telephone communication is desired between stations on a power transmission system, there are three ways in which it can be provided. The most common method in use today is to erect a telephone line between all stations on the system, and use regular wire telephony.

The second method is the application of radio telephony which requires no interconnecting wires for successful operation.

The third method utilizes the existing power circuits to carry the communication, and is known as carrier current telephony.

The relative merits of the first two methods are fairly well known, whereas very little has been published to date on the third or carrier method. Therefore, the outstanding question is "What are the features of carrier telephony which make it especially well adapted to this class of communication?"

In considering this question, it is advantageous to outline, in a general way, how carrier current telephony is accomplished.

First: There is provided a source of relatively high frequency alternating current of constant amplitude. This is usually produced by a pliotron in conjunction with an oscillating circuit. The high frequency current thus generated is known as the carrier.

Second: Suitable means are provided for controlling the amplitude of this carrier. It is moulded into an electric current varying in accordance with the sound waves set up by the voice. This action is commonly called modulation.

Third: This modulated carrier current is transferred to the overhead transmission lines which serve as the conducting channel. It is superimposed directly on the current normally carried by these lines, thus obviating the necessity of a separate communication circuit. A single wire, one or two tower lengths, is usually used for this purpose. This is called the coupling wire.

Fourth: The carrier current thus transferred to the power lines is guided by them to the distant receiving stations, instead of being broadcast in all directions as with radio.

Fifth: The current arriving at these receiving stations is drained from the power conductors by a coupling wire. Suitable circuits, selective to the carrier frequency only, are used in order to suppress the lower frequency power current.

Sixth: The received carrier energy is converted into sound waves of the same character as those produced by the speaker.

The first, second and third are accomplished at the transmitting station, the fifth and sixth at the receiving stations. The fourth, however, is provided by *the existing power circuits* connecting the various stations on the system.

Thus, carrier telephony combines the chief advantage of each of the other two methods, without the corresponding disadvantage of either. Namely, the advantage of radio—that a special circuit is not required —is combined with the advantage of wire telephony, that directive transmission is obtained.

There are a number of other important features of the carrier system. The quality, for example, is in most cases better than that obtained on the wire line. When unusual precautions are taken with the wire lines such as use of a separate pole line, frequent transpositions and drainage, then the quality obtained during normal operation is about the same with either type. Actual tests have shown, however, that even on a system where all precautions were taken the carrier was many times superior during cases of short-circuit and grounding of the power conductors. Since it is during the time of trouble that communication is most needed, this advantage of carrier is obvious.

The quality obtained with radio and carrier are practically the same.

The hazard of accidental contact with the high-voltage line is many times greater with the wire telephone than with the carrier, except in cases where the telephone wires are on a separate pole line. The coupling wire used at each end is only a fraction of a mile in length, whereas the telephone line must extend throughout the entire distance. The coupling wire is usually somewhat closer to the h-v. lines than the telephone circuit, thus increasing somewhat the probability of accidental contact with the h-v. line. This possibility is reduced considerably by using the same conductor and spacing as employed for the h-v. lines. In this way the chance of contact between coupling wire and line is made as small as that of contact between lines. The same general form of protection is used on both the wire line and coupling wire, so that they are equally capable of withstanding accidental contact.

Some further advantages of carrier over radio telephony for this class of communication are brought about by the directiveness of carrier transmission. A radio station transmits almost uniformly in all directions whereas the carrier is confined to the h-v. lines. This results in far greater power being received at the distant point for a given input at the transmitter, or conversely the same received energy for a lower transmitted power. For this reason, reliable calling or ringing can be provided far more economically with carrier than with straight radio, thus eliminating the need for an operator on watch, twenty-four hours each day.

Privacy to the extent of the system and very little interference to external communication circuits are two direct results of the carrier's confinement to the h-v. lines. This also makes it possible to operate the carrier stations without a license or licensed operator. The costly towers required for a radio antenna are not required for the carrier system since the coupling wire is suspended directly from the existing transmission line towers.

From the foregoing, it is obvious that carrier telephony is very well adapted to communication between power stations over power transmission lines.

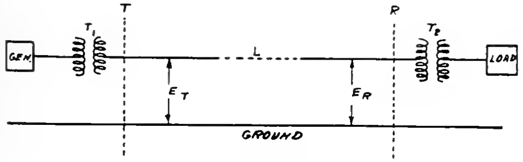

Fig. 1. A Fundamental Transmission System

Technical Features

In order that the operation of carrier telephone equipments under actual service conditions be better understood, it is desirable that some of the technical features be considered.

Fig. 1 represents a simple power transmission system. L is the transmission line between the generator station and the load. T_1 and T_2 are transformers connecting the power apparatus to the line. T and R represent the points between which carrier communication is desired. For simplicity, only one transmitter T and one receiver R will be considered.

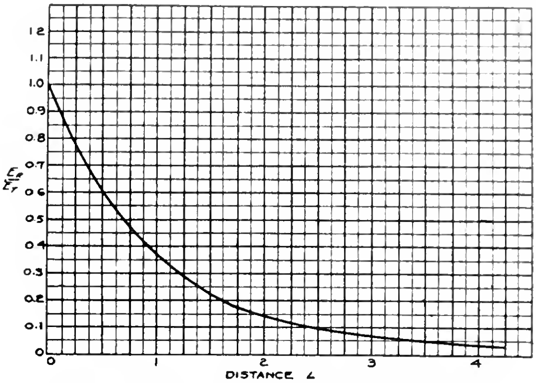

Fig. 2. Variation of Received Voltage with Distance
E_T = Transmitted voltage E_R = Received voltage

Any voltage E_T impressed on the line at T will result in a voltage at R. This voltage represented by E_R will be less than the impressed voltage. The value of E_R can be determined, if the circuit constants are known. Neglecting, for the present, the effect of the power transformers T_1 and T_2 and assuming that the proper terminal impedances are provided at T and R, then E_T will cause a voltage E_R at the receiving station, which is governed by the following relation:

$$E_R = E_T \, e^{-aL} \qquad (1)$$

where L is the length of line, and a is the attenuation constant determined by the resistance, leakage, capacitance and inductance of the line.

In the case of a uniform line of constant attenuation, the voltage received varies with distance in the manner shown in Fig. 2.

Another interesting curve is plotted in Fig. 3. This shows the variation in impressed voltage with increasing distance for a given received voltage. The attenuation is assumed to be constant, as in Fig. 2. This curve shows quite clearly that the impressed voltage required varies at a greater rate than the distance. This factor is of considerable importance when considering extensions to existing carrier systems.

Uniform lines properly terminated are seldom, if ever, met when applying carrier to existing power transmission lines. This is primarily due to the effect of shunt transformers, intermediate taps, and the difficulty of coupling to the h-v. line with a carrier circuit of the proper impedance to fit each particular line.

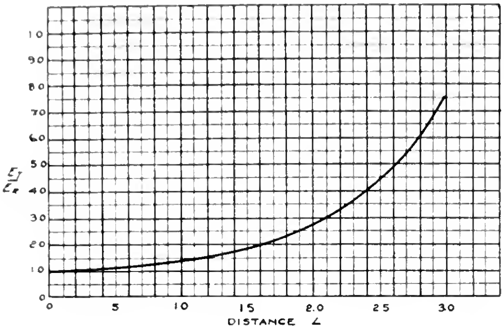

Fig. 3. Variation of Required Impressed Voltage with Distance for a Given Signal Strength

E_T = Transmitted voltage E_R = Received voltage

The equivalent circuit of a simple system is shown in Fig. 4. T and R represent the carrier stations. Z_1 and Z_2 represent the impedances of the power transformers at the carrier frequencies. These transformers are represented with one side grounded. This represents the general case since practically all transmission systems are grounded, either directly through an impedance or by capacity effects. The value of these impedances varies with the load on the low-voltage windings of the transformer. For the simple arrangement shown, the impedance of the high-voltage side varies approximately as the square of the voltage ratio of the transformer. Thus, if the impedance of the low-voltage side is 100 ohms and the voltage step-up is in the ratio of 1 to 10, then the effective impedance is approximately $10^2 \times 100$, or 10,000 ohms.

Since the type, capacity and load vary considerably from station to station and from time to time it is obvious that fixed relations cannot be established. Actual measurements on certain transformers have indicated that, in the majority of cases, the impedance of the transformer at the frequency used is relatively high compared with the rest of the elements under consideration. The energy which the transformers absorb from the circuit will then be relatively small.

The impedance of h-v. lines varies considerably with the number of circuits, arrangements on the towers, etc. As in other cases, the impedance of the output and input circuits should be matched for the maximum energy transfer. Accordingly, the most desirable conditions will exist when both the carrier transmitter and receiver circuits Z_T and Z_R, respectively, have an impedance equal to the characteristic impedance of the lines. Furthermore, it would be advisable that the impedance of all transformers and other power apparatus on the line be of such a high value that they would act essentially as an open circuit to the carrier current.

We have just shown that the impedance of the power transformers is relatively high compared with the line impedance. Regardless of the relative values, neither can be altered appreciably without the use of costly and rather undesirable apparatus.

The problem then becomes one of designing a coupling arrangement which will most efficiently impress carrier on the h-v. line at the transmitting station and absorb carrier from the h-v. line at the receiving station. Any arrangement which will provide for an efficient transfer of energy between the line and coupling wire will serve equally well at the transmitting or receiving stations.

Coupling through instrument transformers, power transformers, high-tension condensers and paralleling wires have all suggested themselves. These methods have been tested. The best method to be used is determined by the operating conditions at the power station, and the cost of the equipment required.

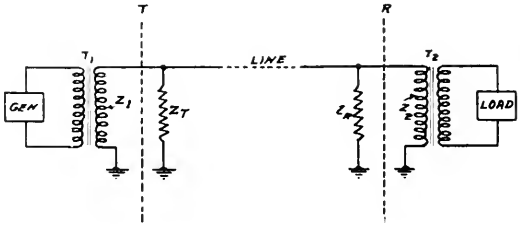

Fig. 4. Equivalent Circuit of a Simple Transmission System

Fig. 5 shows a typical arrangement of the circuits at a power station. A, B and C are the three incoming phases of the h-v. line. S, S_1 and S_2 are air break disconnecting switches which permit grounding of the lines when disconnecting from the station bus. Current transformers, $C.T.$, are shown in each of the three lines. The neutral of the transformer is shown metallically grounded. Actual conditions will vary somewhat from these outlined, but will not alter the general method of operation which is under consideration at this time.

Normal operation is with the switches S, S_1 and S_2 closed. However, in cases of trouble on the lines, they are disconnected and frequently the lines are grounded. Thus, two widely different sets of conditions must be met.

In the first case, the lines are ungrounded and connected to the power transformer windings. These windings offer a relatively high impedance to the carrier current. When the switches are opened and the lines grounded, the impedance offered to the carrier is relatively small. This impedance is only that offered by the lines between the point of grounding and the station ground.

Fig. 6 shows the equivalent circuit. Since the conditions on the three lines are similar, only one line is shown. The lines are represented by units of series and shunt impedances, which determine the characteristic impedance of the line, Z_0.

During normal operation, the switch S is in the lower position connecting the transformer winding Z_1 in parallel with the carrier equipment, represented by E_T. As previously pointed out, the impedance Z_1 is usually relatively large compared with Z_0.

When the switch is in the other position the impedance Z_1 is reduced to zero. The only impedance offered by this circuit is that of the line between point A back through switch S to ground. This impedance is usually very low compared with Z_0, so that the line and carrier are effectively short circuited.

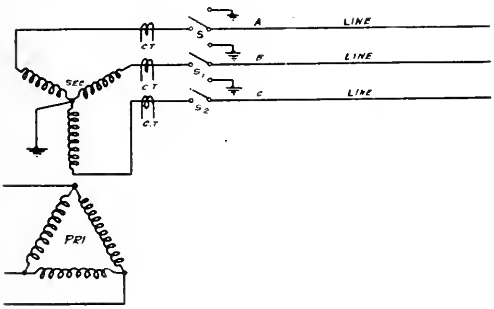

Fig. 5. Circuit Arrangement at Power Station

Two solutions are obvious. The voltage can be introduced in series with the line by opening switch S_4, thus feeding from carrier generator E_S. This is quite satisfactory for operation with grounded lines, but has the disadvantage previously mentioned, that E_S must be sufficiently high to work through impedance Z_1 of the transformer when in circuit.

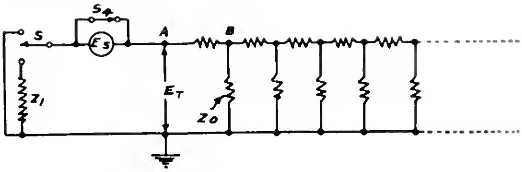

Fig. 6. Equivalent Circuit of Power Station Arrangement

The other solution is to apply the voltage in shunt as with E_T only at a point B sufficiently far out on the line so that the impedance of the ground path is increased to a value comparable with Z_0.

Since any method of coupling employed must be satisfactory under both normal and abnormal conditions in the station, it is obvious that the second solution is the one to be used.

The problem of impressing the carrier voltage on the line at any point is quite involved. Any apparatus directly connected to the h-v. line must be insulated to withstand not less than two or three times the operating voltage of the line. The cost of such equipment as condensers or transformers is so high for lines above 33,000 volts that it is seldom economical to use them. Furthermore the disadvantage arising when the lines are grounded from coupling at a point within the station also influences the decision not to use direct coupling equipment.

The use of a parallel coupling wire solves both of these difficulties. It is relatively inexpensive, since it need only be insulated for low voltage, and can usually be constructed from material available at the power station. It can be made sufficiently long so that part of the carrier energy is impressed on the line at quite a distance from the point of grounding, thus grounding the lines in the station is made relatively ineffective.

The chief disadvantage of this method of coupling is low efficiency. This can best be seen by reference to Fig. 7. The capacitance of the coupling wire to ground is represented by EC_2, of the coupling wire to the h-v. line by EC_1, and the h-v. line to ground by EC. ER represents the effective resistance of the circuit. E_T and I_T are the carrier voltage and current into the coupling wire.

I_1 represents the portion of the current induced in the h-v. line which leaks back into the station, while I_2 is the current on the h-v. line actually passing the end of the coupling wire toward the receiving station.

The voltage E_T causes a current I_T to flow which divides inversely in proportion to the impedances offered by the capacitance EC_1 and EC_2. Since EC is large in comparison with EC_1, it can be neglected for the present.

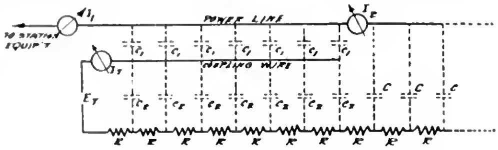

Fig. 7. Equivalent Circuit of Coupling to Line

The current passing through EC_1 into the h-v. line represents useful energy, whereas that absorbed by the coupling wire capacitance to ground is lost, dissipating itself in the resistance of the circuit.

An example of a typical coupling wire will show the low efficiency effect quite clearly. A coupling wire 1000 ft. long, and 40 ft. above the ground and 10 ft. from a single h-v. line has an electrostatic capacitance of approximately 0.002 microfarads to ground and 0.0009 microfarads to the overhead wire. Thus the current divides, approximately 55 per cent passing to ground directly and only 45 per cent being transferred to the line.

In practice there are usually three or more conductors in the h-v. line so that this ratio is somewhat improved.

The maximum efficiency will obtain when the impedance of the carrier circuit equals the effective impedance of the carrier equipment. This condition can only be approached with this method of coupling. Increasing the length of the coupling wire decreases the impedance between it and the line. However, at the same time it results in an increase in the capacitance between the coupling wire and ground. Thus more energy is required from the carrier generator to charge the coupling wire to the same potential. It is obvious that a limit will be reached beyond which it is not advantageous to extend this wire.

Experience has indicated that a good average length for the coupling wire is approximately 1000 to 2000 ft. This length has also been sufficient to reduce to a workable value the effect of grounding the lines at the station.

The factors governing the erection of coupling wires to provide the maximum efficiency may be summarized as follows:

1. The wire should be kept as far above the ground as possible.
2. The distance between the coupling wire and all lines should be made as small as possible consistent with safety. The usual spacing is that used between phases of the line.
3. The coupling wire should be at least 1000 ft. long.
4. The coupling wire should be brought to the carrier equipment by the most direct path. The uncoupled portion or lead-in tends to increase EC_2, Fig. 7, without increasing EC_1, thus lowering the efficiency.

As previously stated, any arrangement used to transfer energy to the line will serve well to absorb energy from it. Accordingly the factors summarized above apply to the erection of a coupling wire for reception as well as for transmission.

Fig. 8 shows a typical coupling arrangement with its protective equipment. The coupling wire is connected through the lead-in to a high-voltage low-current fuse, F. This point is connected to the ground through a horn gap, a drainage coil and the carrier equipment.

The impedance of the drainage coil L_1 is very low at the power frequency, but extremely high at carrier frequencies. It will, therefore, drain off the static charge that accumulates on the coupling wire without absorbing power from the carrier equipment.

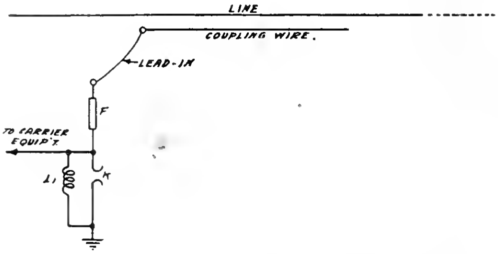

Fig. 8. Schematic Diagram of Coupling Equipment with Protective Apparatus

In the case of momentary contact between the h-v. line and the coupling wire, the choke L_1 will pass enough current to blow the fuse F. In case of a steep wave front the voltage across L_1 might rise very rapidly. The horn gap K will discharge to ground, until the fuse has time to blow, thus limiting the voltage across the carrier equipment.

The chance of contact with the h-v. line is very slight as pointed out in the introduction. However, this protective equipment is supplied as additional insurance against possible damage.

In practice simple systems such as the one thus far considered are very seldom, if ever, met. For example, there are usually a number of transformers tied on at intermediate points along the line. The effect of these transformers is the same as previously outlined for the terminal transformers. Unless they are of large power capacity and have heavy secondary loads, the carrier loss is small. A rough approximation of the effect has been established. Every intervening transformer station is considered as the equivalent of 10 miles of line added to the actual distance. A line 40 miles long with three intervening transformer stations would then be said to have an equivalent length of 70 miles.

It is also obvious that more power will be required for communication over a given distance if the line divides or branches off at an intermediate point. The energy arriving at this point not only divides in inverse proportion to the impedances of the two circuits, but also some of the energy is reflected due to the change in the constants of the line at that point.

The equivalent of a tie-in in miles of line depends largely upon local conditions. The usual figure used is from 10 to 25 miles depending on the extent of the system.

Another form of loss which must be considered is the effect of one carrier receiver on another. This condition is illustrated in Fig. 9. In this case 1, 2 and 3 are carrier stations coupled to the line. When Station 1 is calling Station 3, the intermediate Station 2 will absorb some of the carrier. The usual procedure is to lessen the coupling to the line at Station No. 2. This is possible due to the shorter distance involved. The coupling is reduced to a value consistent with successful operation from Station No. 2, and at the same time minimizing the effect produced on communication between the two extremes.

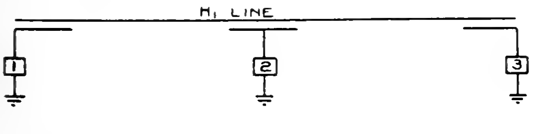

Fig. 9. Schematic Diagram of Three-station Communication System

A closed metallic path is not required for successful carrier communication. The impedance offered to the carrier in passing from the coupling wire to the line is relatively low, while to audio frequency telephone current it would be practically infinite.

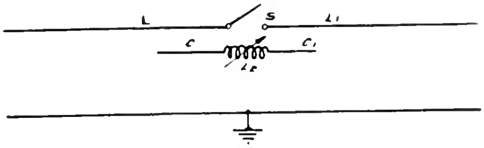

Fig. 10. Schematic Circuit of Gap-bridging Equipment

However, for a given carrier voltage impressed at the transmitting station, the received voltage will be determined to a large extent by the impedance offered by the intervening path. Thus, if the impedance is high, due to breaks in the lines, open switches, intervening transformers, etc., the received voltage will be appreciably less than in the case of a direct unbroken circuit.

Tests have been made which indicate that all lines except one can be disconnected and grounded not only at the terminals, but also at an intermediate point without interfering with carrier communication. It is also known that five out of six lines can be opened at an intermediate point with the same result as before.

It is obvious from the foregoing that definite assurance cannot be given regarding the operation of carrier through breaks in the line. The only statement which can be made is that if the break is of such a character that the normal carrier frequency path is not completely opened or made too high in impedance then communication will still be possible.

There is another gap met on transmission systems known as the predetermined type such as open switches, step-up transformers, frequency changers, etc. This gap is definitely located and its magnitude known.

A method has been developed for bridging gaps in this class. Fig. 10 shows the most common method in use. L and L_1 are h-v. lines separated from each other by switch S. C and C_1 are wires erected parallel to L and L_1 respectively. The exposure in each case is in the order of 2000 ft. L_2 is a tuning inductance which is adjusted to neutralize the capacitance of the coupling wires. In this way the impedance across switch *S*, which was practically infinite, can be reduced to a much lower value due to the presence of this series tuned circuit between the two lines.

Successful operation has been obtained between stations on independent lines crossing each other at right angles, when coupled together through this form of gap bridging equipment. This method is equally applicable to bridging the other forms of predetermined gaps mentioned above.

Another obstacle is met in carrier transmission when high-tension cables rather than aerial lines are used to carry power between stations desiring carrier communication. High efficiencies cannot be obtained because of the tremendous increase in power required to charge the cable to the required potential. Carrier communication is possible over short lengths of cable if specially designed equipment is used.

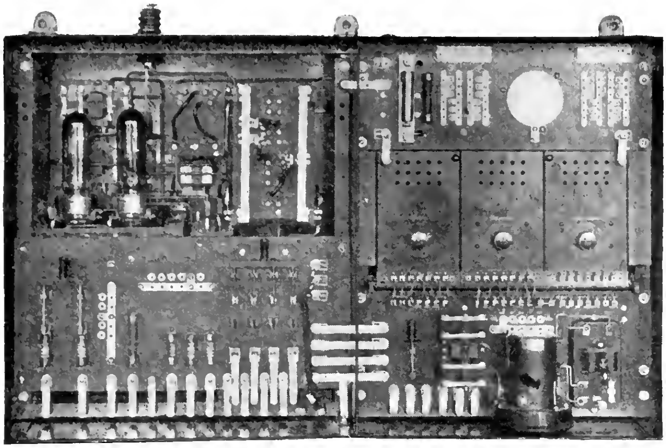

Fig. 11. Transmitter-receiver for 50-watt Carrier Current Telephone

Not over two or three per cent of the total number of power companies actively interested in carrier have presented conditions involving high-tension cables.

The influence of the power circuits and apparatus has been outlined briefly above. The effects may be summarized as follows: The more intricate and complex a power transmission system, the greater the power required for successful communication. Accordingly, all conditions must be known in detail before outlining a carrier communication system.

Carrier Equipment

The equipment required for carrier telephony is similar to that used for commercial radio telephony. The circuits used, although modified to fit the somewhat special conditions of carrier service, are essentially those used in radio equipments. The most essential difference is the ringing feature incorporated in the carrier equipments. This is very seldom furnished with radio equipments.

Fig. 11 shows the transmitter-receiver cabinet supplied with the 50-watt simplex carrier current telephone and calling equipment. This equipment is rated for communication over 85 equivalent miles.

This cabinet is divided into two compartments. The receiving apparatus is mounted in the compartment on the right and the transmitting apparatus on the left.

The receiver is further subdivided into the tuned coupler in the top section, the three vacuum tube units in the center section and the calling and control apparatus at the bottom.

The transmitter compartment contains the generating and modulating units and their accessories. A small panel is provided across the bottom of this compartment to mount switches, fuses and controls. Power for the transmitter is supplied from a motor generator operated from the station supply. The receiver is supplied from a 6-volt storage battery. These units are shown in Fig. 12 along with a spare storage battery and charging equipment.

The three units shown in Fig. 13 are located conveniently to the station attendant. They are the operator's desk stand, and control unit, a terminal box, and the calling bell.

The control unit on the side of the desk stand contains a three-position key, self-restoring to the neutral position. When in the neutral position this key controls circuits which place the carrier equipment in the receiving condition so that the station attendant can hear the speech from the remote transmitter.

When this key is held in the lower or talk position, the apparatus is automatically re-connected for transmission. This method of operation is known as simplex in comparison with the duplex method which does away with this control.

The upper position is used in sending out calling impulses. Code combinations are used to select stations when there are more than two on the same system.

A lead covered cable is also included with this operator's control equipment to connect it with the transmitter-receiver cabinet. Experience has indicated that the distance between the transmitter-receiver cabinet and operator's control is seldom, if ever, in excess of 250 ft. Accordingly, the circuits were proportioned for distances up to 250 ft. Special provision is then made for distances in excess of this.

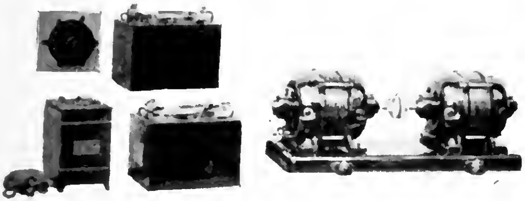

Fig. 12. Fifty-watt Carrier Current Telephone Equipment; Rectifier, Storage Batteries, and Motor-generator

Fig. 14 shows schematically the circuit used in the carrier transmitter for telephony. The functions of the coupling wire and its protective units F, K and L_1 have been given.

Switch S serves to connect the coupling equipment to either the transmitter or receiver. Condenser C and the oscillation transformer L_2 in conjunction with the coupling wire determine the frequency of the carrier current generated by the oscillator. C_1 and R are grid leak (resistor and condenser) providing the proper grid bias potential for the oscillator. C_2 is a condenser blocking the 1000-volt d-c. from the output system.

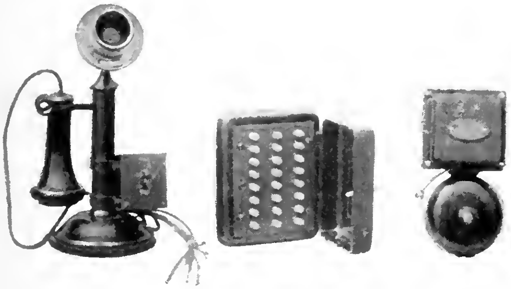

Fig. 13. Fifty-watt Carrier Current Telephone Equipment; Desk Telephone, Terminal Box and Calling Bell

Two 50-watt pliotrons are used, one as an oscillator, the other as a modulator.

Inductance L_3 and condenser C_3 are adjusted to parallel resonance at the carrier frequency. A very high impedance is offered to this carrier, thus preventing its absorption in the modulator and generator circuits. This trap circuit is so designed, however, that it does not suppress to any appreciable extent the audio frequency variations caused by the modulating system.

L_4 is the customary plate reactor used with this method of modulation. E is a biasing potential impressed on the grid of the modulator tube to hold it on the proper portion of the characteristic curve. T is a microphone transformer stepping up the voltage variations produced by the microphone M and impressing them on the grid of the modulator tube. This circuit operates in the same manner as in radio transmitters so is quite generally known.

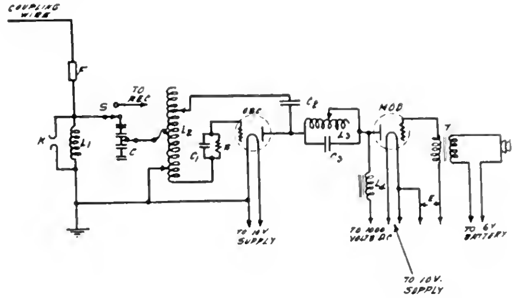

Fig. 14. Circuit Used for Telephony, 50-watt Transmitter

The circuit used for calling is the same except that only the portion shown in Fig. 15 is effective. It will be noticed that control is no longer accomplished by the modulator. In its stead a contact is introduced in the grid leak circuit to control the output of the carrier generator. These contacts are operated by the three-position key at the desk stand when in the call position.

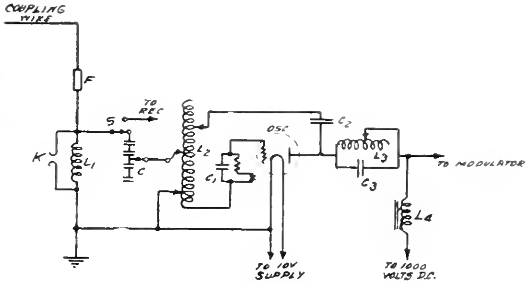

Fig. 15. Circuit Used for Calling, 50-watt Transmitter

The receiver circuit used for telephony is shown schematically in Fig. 16. This is a typical tuned coupler, detector amplifier connection.

C_5 and L_5 are the primary tuning capacitance and inductance used to resonate the coupling wire to the incoming carrier frequency. Coil L_6 is coupled to this primary circuit and is also resonated to the carrier frequency by condenser C_6. R_1 and C_4 are the usual grid leak resistance and condenser.

PR-1-B pliotrons are used both for the detector and amplifier. The filaments are energized from a 6-volt battery. One quarter ampere is required from the battery for each tube. The plate is supplied from a 44-volt battery of dry cells.

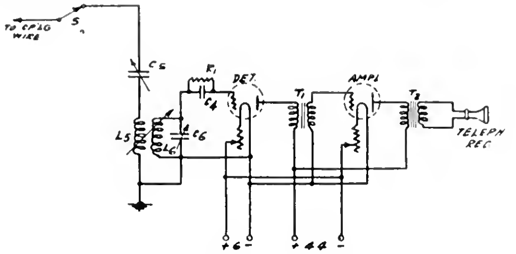

Fig. 16. Receiver Circuit Used for Telephony

The output of the detector tube is supplied to the amplifier through an intervalve transformer T_1. This tube further amplifies the signal which is reproduced by the telephone receiver through a step down transformer T_2.

The circuits are so arranged that this amplifier may be cut out if not required. Also a second stage of amplification normally used for calling only can be introduced for telephony when required.

The circuit used for calling is shown in Fig. 17. Three tubes are normally used: the first two as carrier amplifiers, the last as a rectifier. Transformer coupling is used throughout. The grid of the rectifier tube is normally held at the rectification point on its characteristic by a biasing potential. The pulsating unidirectional output of the last tube is passed through a sensitive polarized relay, R_2.

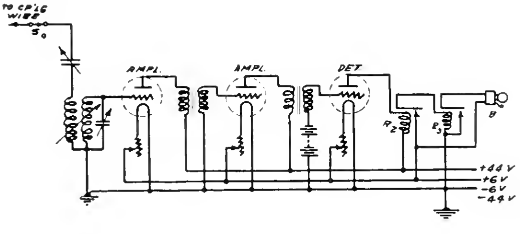

Fig. 17. Receiver Circuit Used for Calling

The contacts of the relay close a local circuit energizing a second relay, R_3, which controls the call bell B.

Suitable switching arrangements are provided to make these circuit changes automatically. There are four conditions in all: Stand-by, Receive, Call and Talk. The first obtains when the receiver is on the hook, and the three-way key is in the neutral or receive position. This is the condition required for the reception of calls. Lifting the receiver from the hook starts the power apparatus and connects the equipment to receive telephony. The other two conditions have previously been described. When the communication has been completed, hanging the receiver back on the hook will automatically shut down the equipment and restore it to stand-by.

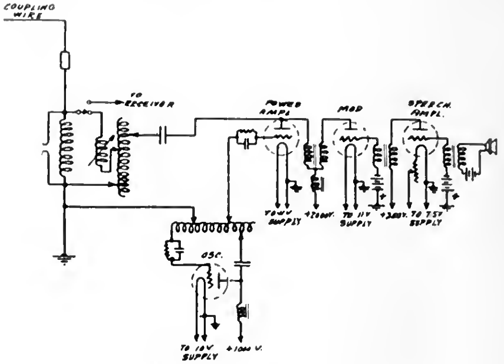

Fig. 18. Circuit Used for Telephony, 250-watt Transmitter

When communication and calling is desired over a greater range than 85 equivalent miles, a higher power equipment is used. The next standard size is a 250-watt equipment, rated at 260 equivalent miles.

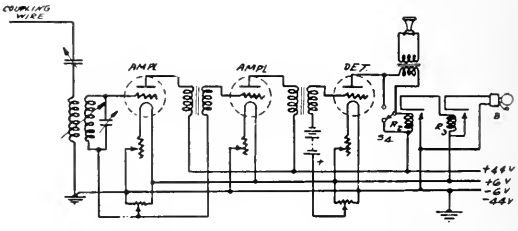

Fig. 19. Receiver Circuit Used in 250-watt Equipment

Since this equipment is somewhat larger than the 50-watt equipment, regular switchboard design is used. The transmitter and receiver are mounted on separate panel structures.

The transmitter circuit differs from that in the 50-watt equipment in one major respect. The carrier generator in the 50-watt equipment is self-excited. In the 250-watt equipment a separate 50-watt master oscillator is used to excite the larger tube which then operates as a power amplifier. The circuit is shown in detail in Fig. 18. It will also be noticed that a fourth tube has been introduced. A PR-2-B pliotron is used to amplify the feeble voice currents set up by the microphone. This amplification is required in the higher power equipment in order that complete control of the carrier be obtained. Also a differential transformer has been substituted for the tuned trap used in the 50-watt transmitter.

The receiver circuit used with the 250-watt equipment is shown in Fig. 19. Three tubes are used at all times, thus somewhat simplifying the switching. Two tubes are used as carrier amplifiers and the third as a rectifier. The same combination and arrangement of tubes are used for receiving both call, signals and telephony. The only changes required when changing from one to the other are: the adjustment of the tuner, the bias potential on the grid of the rectifier and transfer of the output from the relay circuit to the telephone transformer and vice versa.

Some cases have come up where control of the carrier equipment was desired from two separate places. In order to meet this need the operator's control equipment was designed for parallel operation from a second point. The number of extension stations may be increased to three or four, providing the total distance from any one station back to the transmitter-receiver cabinet does not exceed 250 feet.

When control is desired over much longer distances, a remote control unit must be employed. Equipment has been developed especially for this purpose. This equipment consists of suitable control and amplifying equipment to permit control of the standard carrier equipment from a point several miles from the transmitter-receiver cabinet. Four ungrounded conductors are required between the transmitter-receiver cabinet and the point of control.

Several extensions can also be added at the remote point if desired.

Installations

Within the next few months a total of fifty-five 50-watt and sixteen 250-watt installations will be completed. Several installations of the 50-watt equipment have been made to date.

Fig. 20 illustrates one installation. This and another similar 50-watt equipment, although not the first installed, have been in daily operation over a 70,000-volt line 40 miles long, for several months.

Fig. 21 shows the first commercial installation of the 50-watt carrier equipment. This equipment has been in operation with a similar one twelve miles away on a 44,000-volt line. This installation was made during the latter part of November.

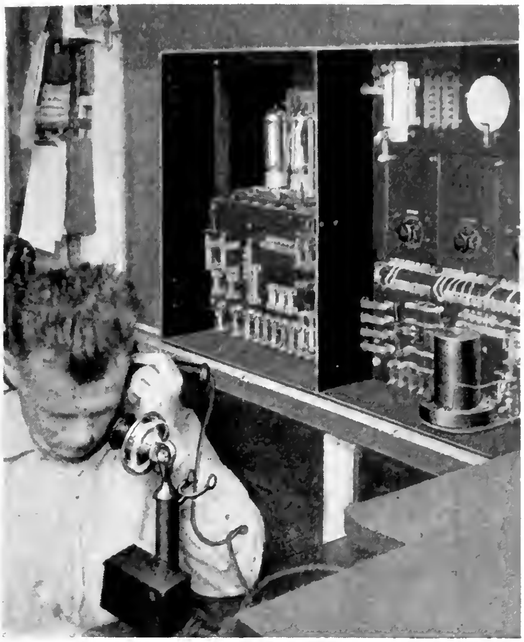

Fig. 20. Fifty-watt Carrier Installation in Substation

Prior to that time an experimental installation was placed in operation over a local power line. The standard 50-watt equipments were used for communication over 27 miles of 33,000-volt line. This circuit is composed of two sections of independent lines tied together by gap bridging apparatus at a point 17 miles from one carrier station.

Considerable experience has been obtained from the installations now in service. The engineering and operating personnel of the various power companies have become familiar with their equipments and the operation of carrier in general. The result is that they have started to outline involved operating requirements which their experience with the simpler system has indicated can be met by more elaborate carrier systems.

FUTURE CARRIER SYSTEMS

Selective Ringing

Extension of the carrier systems to include several stations on one power transmission line has created a demand for selective ringing. The present method of code selection although satisfactory for a limited number of stations becomes inconvenient when many stations are added. A selective ringing attachment to the existing equipments will shortly be available. The value of making this equipment in attachment form is obvious, since existing systems can be so equipped when extended to a point where code selection is undesirable.

Duplex

Up to the present time, all commercial installations have been made for simplex operation. This was the more economical and least involved method. Much has been said regarding the inconvenience of simplex operation as compared with duplex.

The consensus of opinion obtained from the operators and dispatchers who have used the equipment is almost entirely favorable to simplex operation.

The one real objection to the method now in use for providing simplex is that the operator's hand is required at intervals to operate the control key between talking and listening periods. This may be overcome by the use of a foot operated switch now available for the purpose.

The other objection raised at times appears to be of no consequence to the operators who are actually using the equipment. That is the inability to interrupt the speaker. This feature appears unnecessary when handling the usual class of communication on power transmission systems.

As is well known, the problem of duplex operation consists of preventing the local transmitter from paralyzing the local receiver to an extent that it is no longer responsive to signals from the remote transmitting station. Any number of methods have been proposed, each having its merits and demerits. Experience has indicated that, among other precautions, it is usually necessary to operate the equipment at two frequencies in order to differentiate between the local and remote signals.

The equipment required for such service, although more involved than for simplex, is not really the limiting factor.

Considering the problem broadly, the useful frequency range for carrier transmission is probably between 12,000 and 100,000 cycles. Certain portions of this range are now in use for high-power radio telegraph and existing carrier systems. If the remaining ranges were all available for duplexing one power company's systems the problem would be solved. This, however, is not the case.

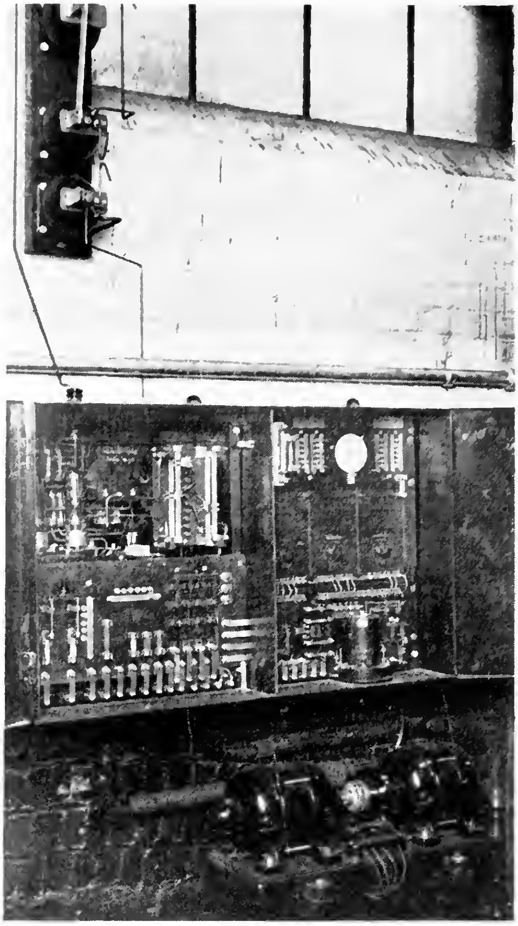

Fig. 21. First Commercial Installation of 50-watt Carrier Equipment

The ever increasing trend of power companies to interconnect their systems changes the aspect of the situation considerably. Several instances have come up where four and five interconnected companies are or shortly will be equipped with carrier communication systems, each to operate without interference to the others.

This is just the beginning of the interconnection of power systems. In order to provide for the conditions which will have to be met on the mammoth networks of the future, it is necessary that the frequency bands be very carefully chosen and assigned. The groups of four and five interconnected systems now under consideration require a considerable portion of the available frequency range for simplex operation. Any attempt to employ duplex by means of frequency selection would further reduce the range available for extension of the communication system.

The frequency range is sufficiently broad if the individual bands are properly assigned and are not used unnecessarily. For these reasons, it is believed that the advantages of duplex over simplex in the majority of cases is not sufficient to warrant jeopardizing the expected usefulness of carrier communication to the power companies.

Frequency Converter Ties Between Large Power Systems

By J. W. Dodge

Lighting Engineering Department, General Electric Company

With the advent of the "superpower zone" some means must be used of making power of various frequencies available over large areas; this lends added importance to the various types of frequency changers. The author describes the various types of frequency changers, discusses their relative merits and their fields of application.—Editor.

The expansion of power systems throughout the country is leading to the tying together of a great many of these systems, forming large interconnected systems similar to the proposed "Superpower System" covering the territory from Boston to Washington. Due to the variety of frequencies used, it is often desirable to tie two systems of different frequencies together, and this has led to the development of several types of frequency converters to meet special requirements.

Each type of frequency converter has a rather definite and well defined field of application, and it is the purpose of the present article to describe the available types of frequency converters and their application to power systems.

Types of Frequency Converters

For convenience let us use the following terms in discussion of different types of sets:

1. A *synchronous set* we will consider as consisting of a synchronous motor driving a synchronous generator.

2. An *induction motor set* we will consider as an induction motor driving a synchronous generator.

3. A *speed regulating induction motor set* we will consider as a wound rotor induction motor with Scherbius speed control, driving a synchronous generator.

4. An *induction-synchronous set* will consist of an induction type frequency converter direct connected to a synchronous machine. In other words, it is a wound rotor induction machine operated at a definite slip (determined by the speed of the synchronous machine) so that the higher frequency system is connected to the stator circuit, and the lower frequency system is connected to the rotor circuit of the induction machine and also to the synchronous machine. This type of set is entirely synchronous in operation, although it makes use of an induction machine.

5. A *synchronous converter type set* will consist of two synchronous converters operated in series, converting a-c. to d-c. and then back to a-c. of another frequency.

Any of the above mentioned sets are reversible, that is, they may be used for power flow in either direction. Parallel operation* will not be discussed, as it has little bearing on the subject at hand.

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*See "Parallel Operation and Synchronizing of Frequency Converters," by O. E. Shirley, G.E. Review, February, 1920, page 136.

Synchronous Sets

The frequency converter, consisting of two synchronous machines, is the most common and familiar type for large power use. It gives a power tie between the two systems which it connects and forms a rigid frequency tie. The ratio of frequencies of the two systems must remain the same as long as this type of set connects the two together. Any variation in this ratio will overload the set and cause it to pull out of step. Synchronous machines of this class are normally designed for at least 50 per cent momentary overload before the pull out point is reached. This means that momentary fluctuation in frequency ratio may occur and still maintain synchronous operation of the set, provided this fluctuation in frequency does not load the set above the pull out point, and provided the frequency change is of very short duration.

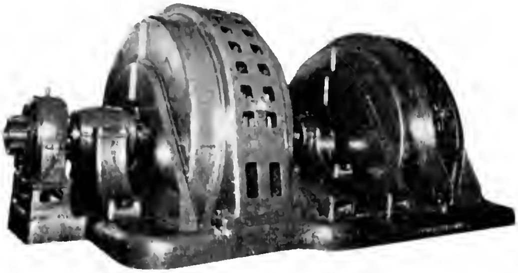
Fig. 1. A 10,000-kw. 450-r.p.m. Synchronous Type Frequency Converter Consisting of a 12,000-kv-a. 30-cycle Machine Direct Connected to a 16,000-kv-a. 60-cycle Machine. A 60-kw. direct-connected exciter is provided for each machine

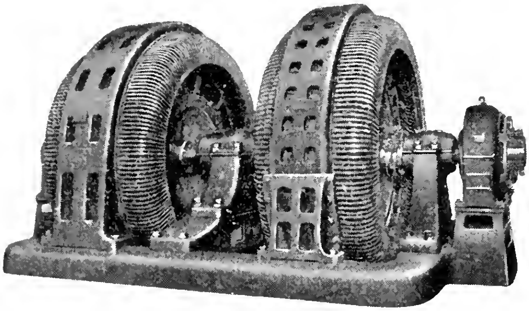
Fig. 2. A 5000-kw. 300-r.p.m. Synchronous Frequency Converter, 25 to 60 Cycles, with Direct-connected Exciters

Synchronous sets may be provided with low resistance amortisseur windings which will make them self-synchronizing, so that in the event of an overload which pulls the set out of step, the machine which is operating as a motor will pull back into synchronism as soon as the load is sufficiently decreased (and with excitation removed). This feature is covered in detail by another article in this issue of the REVIEW, by Mr. O. E. Shirley.

The synchronous frequency converter does not form a voltage tie between systems. The only effect upon the voltage of either system is that of adding one generator (or synchronous motor) of the rating of the set, to each system. It may help to maintain voltage by the addition of a certain amount of kv-a., but gives no voltage tie between systems. Figs. 1, 2 and 3 show synchronous sets suitable for use on large power systems.

Induction Motor Sets

Sets consisting of an induction motor (either squirrel cage or wound rotor) driving a synchronous generator are very similar in operation to the synchronous type of set, except that the frequency ratio varies slightly with load on the set, due to the slip of the induction motor. This does not allow the use of exactly synchronous speed on both systems, and this fact, together with the lower power-factor and efficiency of the induction, as compared with synchronous, sets leads to the choice of the latter in the great majority of cases.

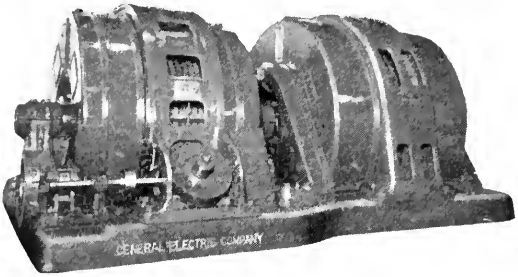

Fig. 3. A 2000-kw. 750-r.p.m. Synchronous Frequency Converter, 25 to 62½ Cycles, Showing Semi-enclosed Construction and Stator Shifting Device

Speed Regulating Induction Motor Sets

The Scherbius type of speed control for operating induction motors* above and below synchronism has been used for several years where large variable speed induction motors are required. This method of speed control has recently been considered for frequency converters in order to obtain a

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*See "Speed and Power-factor Control of Large Induction Motors," by J. I. Hull, G.E. REVIEW, July, 1920, page 630.

set which can be operated between two systems where the frequency ratio may vary between such wide limits as to make the operation of a synchronous set impractical.

The principal elements and connections of such a set are shown in Fig. 4. The equipment consists of the main frequency converter set and an auxiliary speed regulating set. The frequency converter is made up of an ordinary synchronous generator and its exciter, a wound rotor induction motor, and an ohmic drop exciter. The speed regulating set consists of a squirrel cage induction motor and a polyphase commutator motor with shunt field excitation, called the regulating motor. This regulating motor is connected across the slip rings of the main induction motor to be controlled, its counter electromotive force opposing the voltage across the slip rings. By varying the excitation of the regulating motor, the slip ring voltage opposing its counter electromotive force may be varied, thereby changing the speed of the main motor. Because of the shunt excitation of the regulating motor, its counter electromotive force, and therefore the speed of the main motor, remains practically constant throughout the entire range of loads for any given setting of the control.

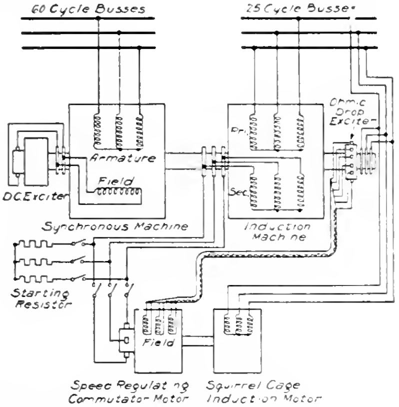

Fig. 4. Simplified Diagram of Connections for Speed-regulating Induction-motor Type Frequency Converter

The ohmic drop exciter mentioned above is a device mounted on the shaft of the main set and used as an automatic source of constant voltage at exact slip ring frequency for the control of the shunt field on the regulating motor. This is shown in Figs. 5 and 6 mounted on the end of the induction motor shaft, and consists of a single primary winding connected to a commutator exactly similar to a d-c. armature, and has collector rings tapped off at 120 electrical deg. intervals (for 3-phase). The secondary is a smooth laminated ring without windings. The theory of operation is explained in the article referred to at the bottom of page 436, by Mr. J. I. Hull. Fig. 7 shows a typical speed regulating set.

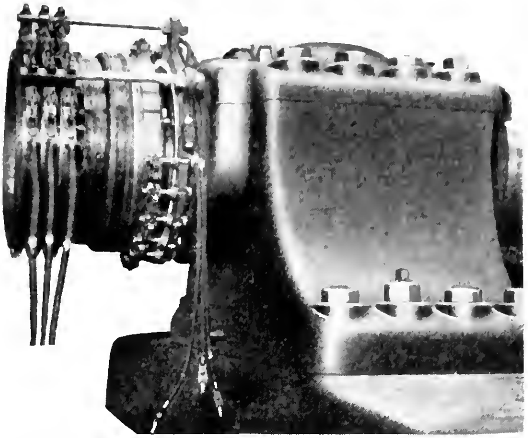

Fig. 5. Ohmic Drop Exciter Mounted on the Shaft of a 2500-h.p. 240-r.p.m. Induction Motor

For motor operation below synchronism or induction-generator operation above synchronism the energy which is taken from the slip rings drives the regulating set causing the squirrel cage induction motor to act as an induction generator and return this energy to the a-c. line, so that the slip energy of the secondary circuit is all returned to the primary line, except for a small loss in putting this power through the speed regulating motor-generator set. With the main motor operating as a motor above synchronism or as a generator below synchronism the power flow through the regulating set is reversed.

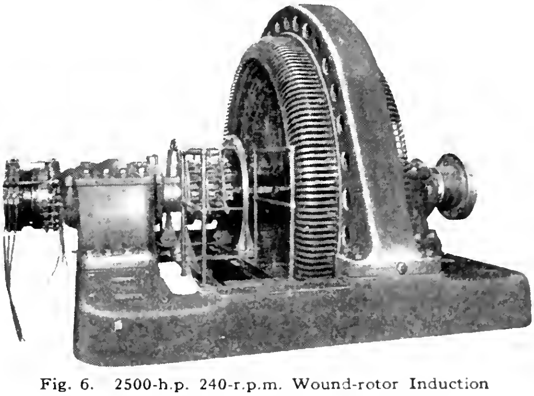

Fig. 6. 2500-h.p. 240-r.p.m. Wound-rotor Induction Motor with Ohmic Drop Exciter

The variation in speed required for a frequency converter is small, probably never exceeding 5 per cent above and below synchronous speed, as no large power system would operate more than 5 per cent above or below normal frequency.

The rating of the regulating set depends upon the speed range required. If S (max), S (min), and S (s) represent the maximum, minimum, and synchronous speeds of the main motor, and Kw (s) be the kw. output of the frequency converter at S (s), then the rating of the regulating set required will be approximately as follows [if the synchronous speed is half way between S(max) and S(min)]

$$Kw\ (\text{reg. set}) = \tfrac{1}{2}\ Kw\ (\text{s}) \times \frac{S(\text{max})-S\ (\text{min})}{S\ (\text{s})}$$

As an example, consider a 10,000-kw., 300-r.p.m. frequency converter with a speed range of 3 per cent above and below synchronism. The approximate size of the regulating set required will be:

$$Kw\ (\text{reg. set}) = \tfrac{1}{2}\times 10{,}000\,\frac{309-291}{300}$$
$$= 300\ \text{kw.}$$

This shows that the regulating set is comparatively a very small unit where small regulation is required, and therefore, would not greatly increase the cost of the frequency converter.

Speed control on the main unit is obtained by adjusting the excitation of the regulating motor shunt field. This is accomplished in a very simple way, and gives a smooth change in speed over the entire range, and does not require any contactor panels or other additional control equipment, other than that described above.

The power-factor of the main induction motor can be controlled by the regulating set so that it is rarely necessary to operate at a lagging power-factor. The equipment would normally be designed to give approximately unity power-factor at synchronous speed and full load. The power-factor is not adjustable at synchronous speed, and varies somewhat with changes in load. When operating above or below synchronism, the power-factor is adjustable and varies with the load on the motor, similar to the operation of a synchronous motor.

It is evident that the principal objections to the induction motor drive have been removed by the addition of the speed regulating set, since it allows the operation of both connected systems at exactly synchronous speed, and the power-factor of the induction machine has been increased to unity or better for the majority of operating conditions.

In addition to correcting the power-factor and speed, it gives a speed control which adds the following distinctly new features:

1. It allows the set to be operated between systems of varying frequency.
2. It allows the control of load on the set by regulating the slip on the induction machine, that is, control of load at the set rather than at the governors of the prime movers on the two systems connected by the set.

Induction-synchronous Sets

For convenience, let us consider an induction-synchronous type of frequency converter for connecting between a 25- and a 60-cycle system. Fig. 8 is a simplified diagram of such a set, consisting of:

1. A wound rotor induction motor having a 60-cycle stator and a 25-cycle rotor (induction frequency converter).

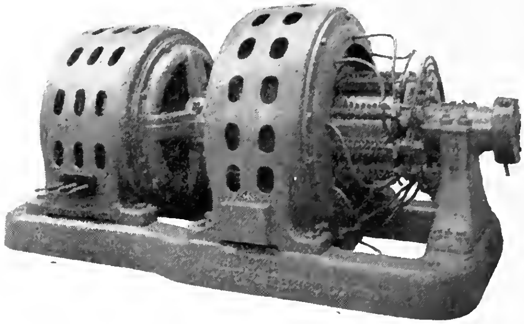

Fig. 7. Double-range Scherbius Speed-regulating Set for Use with a 2500-h.p. Induction Motor

2. A 25-cycle synchronous generator.
3. A direct-connected exciter for exciting the synchronous generator.
4. An induction starting motor.
5. A transformer for stepping up the voltage of the induction motor rotor to 25-cycle line voltage.

A transformer is usually required between the 25-cycle bus and the induction motor rotor because it is difficult to build a high voltage rotor for this machine.

The synchronous machine is a 10-pole, 25-cycle, 300-r.p.m. generator. The 60/25-cycle induction unit is wound for 14 poles, which at 60 cycles would have a synchronous speed of 514 r.p.m. By holding the rotor speed down to 300 r.p.m. with the synchronous generator, we obtain a slip of 214 r.p.m. in the induction machine, which gives 25 cycles at the collector rings of the rotor.

The stator of the induction machine is connected to the 60-cycle line, and the rotor of the induction machine and the stator of the synchronous machine are both connected to the 25-cycle line as shown in Fig. 8.

With this type of a set, consider the 60-cycle machine as a motor and the set generating 25-cycle power. The induction machine will then deliver power both mechanically through the shaft to the 25-cycle generator and electrically through the collector rings to the 25-cycle line.

Neglecting losses, this power will be divided as follows:

1. Power through the shaft $= \frac{300}{514} \times$ (the 60-cycle input to the stator.)

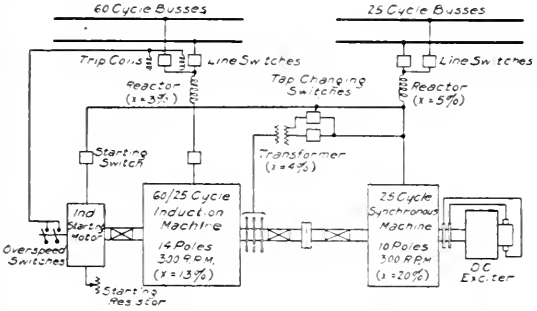

Fig. 8. Simplified Diagram of Connections for an Induction-synchronous Type Frequency Converter

2. The electrical power output through the collector rings $= \frac{214}{514} \times$ (the 60-cycle input to the stator).

Applying this to a set of 35,000-kw. rating, we have:

Mechanical power output through the shaft

$$= \frac{300}{514} \times 35{,}000 = 20{,}400 \text{ kw.}$$

Electrical power output through the collector rings $= \frac{214}{514} \times 35{,}000 = 14{,}600$ kw.

The induction machine furnishes an electromagnetic tie between the 25- and 60-cycle systems, similar to a transformer tie between two parts of a system of one frequency. In other words, this machine forms a voltage tie between systems in addition to being a frequency and power tie, and any variation or disturbances of voltage on one system will be transmitted to the other system through this tie in a manner similar to that obtained through a transformer tie.

The effectiveness of this voltage tie is dependent upon the reactance of the circuit through the induction machine between the two systems. It is also dependent upon the ratio of frequencies of the two systems

If both systems were of the same frequency, the induction motor rotor would be stationary and straight transformer relations would exist. However, if the frequency of the rotor circuit is reduced, the rotor speed increases proportionally and the induced rotor voltage (and therefore the rotor kv-a.) is proportionally decreased. That is, with a 60/25-cycle machine with 35,000-kv-a. input to the stator, the equivalent output of the rotor would be $\frac{25}{60} \times 35{,}000 = 14{,}600$ kv-a.

A 35,000-kw. frequency converter has a reactance of approximately 17 per cent between the two systems to which it would be connected. This reactance is based on the rating of the circuits, that is, 35,000 kv-a. on the 60-cycle side and 14,600 kv-a. on the 25-cycle side. If reactors are used between the machines and the busses, as shown in Fig. 8, this reactance between systems is increased.

With this in mind, let us consider the effect produced with this induction machine tying two systems together when short circuit conditions occur on either system. If a short circuit occurred on the 60-cycle bus and the 25-cycle bus voltage was maintained, a flow of current would occur from the 25-cycle system to the 60-cycle system through the induction machine. Assuming the reactance to be 22 per cent between busses, as shown in Fig. 8, the kv-a. input to the 60-cycle system would be approximately $\frac{35{,}000}{0.22} = 160{,}000$ kv-a. at short circuit. The kv-a. taken from the 25-cycle system under this condition would be $\frac{14{,}600}{0.22}$ $= 66{,}000$ kv-a. (neglecting input to the synchronous machine, which will be comparatively small, being only the power component).

Now consider a short circuit on the 25-cycle system with 60-cycle bus voltage maintained. The kv-a. input to the 25-cycle system from the induction motor rotor would then be 66,000 kv-a. and the input from the 25-cycle synchronous machine would be $5 \times 25{,}000 = 125{,}000$ kv-a. (the reactance of the 25-cycle machine being approximately 20 per cent). This makes a total of 191,000 kv-a. input to the 25-cycle system on short circuit. The kv-a. taken from the 60-cycle bus would be $\frac{35,000}{0.22}=$ 160,000 kv-a.

From the above, it is plain that such a set will tend to maintain voltage on one system at the expense of the other whenever trouble occurs which reduces voltage on either system. This may be very advantageous in some large systems where it is important to maintain service at a reduced voltage during trouble periods, rather than to drop off entirely. On the other hand, this type of set spreads the effect of the trouble over the two systems, pulling down voltage on both when trouble occurs on either one. In this respect, the induction set differs from a synchronous set.

TABLE I

INDUCTION-SYNCHRONOUS FREQUENCY CONVERTERS

CYCLES		POLES		R. P. M.			COMPARATIVE KW. RATING REQ'D		
Motor (Ind.)	Gen. (Syn.)	Motor (Ind.)	Gen. (Syn.)	Shaft Speed	Motor Slip	Syn. Speed of Motor	Induction Motor Stator Per Cent	Induction Motor Rotor Per Cent	Gen. (Syn.) Per Cent
60	25	14	10	300	214	514	100	41.7	58.3
62½	25	6	4	750	500	1250	100	40	60
62½	25	12	8	375	250	625	100	40	60
60	40	2	4	1200	2400	3600	100	66⅔	33⅓
60	40	4	8	600	1200	1800	100	66⅔	33⅓
60	40	6	12	400	800	1200	100	66⅔	33⅓
50	25	4	4	750	750	1500	100	50	50
50	25	8	8	375	375	750	100	50	50
60	33⅓	8	10	400	500	900	100	55.6	44.4
60	30	6	6	600	600	1200	100	50	50
60	30	8	8	450	450	900	100	50	50
60	50	4	20	300	1500	1800	100	83⅓	16⅔
60	50	2	10	600	3000	3600	100	83⅓	16⅔

Table I shows some of the common combinations of frequencies, and the number of poles, speed, and comparative rating of the different parts of the sets, which may be used for induction-synchronous frequency converters. (Ratings given do not take into account the efficiency or power-factor of the set.)

In case of a short circuit on either side of a synchronous set, the unit on the affected system simply acts as any synchronous generator, adding a certain amount of kv-a. to the system. The other system is not affected, except that the load of the set is dropped. In other words, there is no wattless kv-a. exchange between the two systems with a synchronous set, and there is an exchange of wattless kv-a. through the induction set. The need for this kind of a tie between systems should be the primary reason for using the induction-synchronous type of set in preference to a synchronous set.

The induction-synchronous set is normally designed for 1.0 p-f. input and output at full load with power flowing in either direction. This is accomplished by designing the synchronous machine for about 0.85 p-f. lagging load (as a generator) and exciting the induction machine from the 25-cycle machine. The power-factor of the 60-cycle side of the set can be adjusted by changing the ratio of the transformer in the 25-cycle rotor circuit of the induction machine and the power-factor of the 25-cycle side can be controlled by adjusting the field excitation of the synchronous machine.

In general, it is desirable to use current limiting reactors in the lines to the two systems, as it increases the synchronizing power between the two machines of the set, but, as previously stated, the effectiveness of the voltage tie between systems depends upon keeping this reactance down to a minimum. This requires a compromise.

Table I gives some of the combinations of poles which may be used for induction-synchronous sets, also the speeds and comparative sizes of the different parts of the sets. It will be noted that the larger the frequency ratio, the nearer the ratings of the motor and generator come together, while for small frequency ratios the comparative size of the synchronous machine becomes smaller. For instance, with the 60/25-cycle ratio, the synchronous machine is 58.3 per cent of the total rating of the set while with the 60/50-cycle ratio its rating becomes only 16⅔ per cent of the total. The actual kv-a. ratings of machines designed for such sets would vary somewhat from the figures given in Table I, due to consideration of efficiency (or losses) and power-factor. If a transformer is used for the rotor circuit of the induction unit, its kv-a. rating would be the same as that of the rotor.

The synchronous speed of the induction machine becomes very high, as compared with the normal speed of the set, when a close frequency ratio is used, such as 50/60 cycles. This makes it impractical to design a set to stand a runaway speed equal to the synchronous speed of the induction unit, and since there is danger of the set reaching this high speed if the lower frequency circuit becomes disconnected from the collector of the induction machine, it is very important that reliable over-speed protection be provided for opening the a-c. supply circuit to the induction unit stator in case of over speed. This feature is not so important for the sets in which the higher frequency machine has a lower synchronous speed, but such protection should always be provided on this type of set.

Synchronous Converter Type

The use of synchronous converters operating in series for frequency conversion gives a tie between systems which is extremely flexible and in some respects is very similar to both the induction motor set with Scherbius speed control, and to the induction-synchronous type set. It allows the operation of the two systems through a wide range of frequency ratio, allows control of load at the converter, and also gives a voltage tie between systems. This type of conversion apparatus, however, has not received very much favorable consideration for commercial purposes because the cost and maintenance charges are very much in excess of the cost of other types of frequency converters, and the efficiency of such equipment is usually found to be from one to three (or more) per cent below that of synchronous type frequency converters.

Field of Application for Various Types of Frequency Converters

The synchronous type of set is properly applied as a tie between power systems where a power and frequency tie are necessary and where no voltage tie is desired. It is limited to use between systems operating at constant ratios of frequency, and the load over such a set must be controlled by adjustment of governors on the prime movers of the connected systems. It has the advantage of simplicity of construction and operation, over all other types of sets. It is inherently adaptable to rugged and simple design, with a minimum of auxiliary parts. It involves no new or untried types of construction. Its efficiency is probably as good or better than any other type of set (for any given rating), it can be designed to give any desired power-factor on either machine, and the power-factor is easily adjustable by field control. Either machine may be used as a synchronous condenser on its system, when the set is not in use as a tie between the two systems.

The induction motor set is rather infrequently used as a tie between large power systems due to its poor efficiency and power-factor as compared with a synchronous set. It also has the handicap of frequency variation with the load, and of course, the induction motor can not be utilized as a synchronous condenser when the set is not in use as a tie.

The speed regulating induction motor type frequency converter, however, adds a unique operating advantage. This is the characteristic of adjustable frequency ratio on the set, to compensate for varying conditions on the systems connected by the set and the advantage of control of power flow through the set, at the set itself.

An induction motor has a certain inherent speed regulation. In other words, the slip changes with changes in load on the motor. This very important difference between an induction and a synchronous motor makes the induction motor set flexible to slight changes in frequency, simply changing the load on the set where a synchronous set would be forced out of step. The speed regulating set makes it possible to bring the load back to normal after such changes in frequency.

In the past it has been considered impractical to tie certain systems together with synchronous sets because the frequency of one or both systems was so unstable as to cause a synchronous set of reasonable size to trip out frequently on overload, due to these changes in frequency. Such systems are usually those covering large areas geographically and having various size generating plants located at widely separated points, tied together by high-voltage transmission lines. They are mostly hydro-electric plants, and on such systems the voltage and frequency regulation are necessarily large compared with systems consisting of large steam-electric generating plants concentrated in small areas, where very close voltage and frequency regulation are obtained.

It is in tying the former type of system to a system of different frequency that demands a speed regulating type of set. As the frequency ratio varies between systems, the slip of the induction motor can be varied to hold practically constant load on the set. If the frequency changes are slow this adjustment could be manual, while on systems where frequency changes are rapid, an automatic control would be necessary. This could be operated from a contact-making wattmeter arranged to hold constant load on the set. Any changes in load on the set would operate the contact-making wattmeter which in turn would operate the control of the shunt excitation of the speed regulating motor of the Scherbius control set, and raise or lower the speed of the main set as the load demanded. This type of set is, therefore, well adapted to automatic or semi-automatic control.

On systems covering large areas it should be quite an advantage to have the control of load on the frequency converter located at the set. Otherwise the system operator must keep informed as to the load on the set, and instruct his various station operators to change their governor settings to adjust for changes in load on the set.

The speed regulating type of frequency converter has the disadvantage of being more complicated than the synchronous sets, and will usually be found to have a little lower efficiency. The power-factor can usually be maintained at unity or better on the induction machine so that the synchronous motor has little advantage in this respect.

While the frequency converter is a new field for the Scherbius type of control, a great deal of experience has been obtained on this control for steel mill main roll drives where the fitness for the work and the thorough reliability of the Scherbius system of control have been demonstrated by years of very successful operation under the most extreme speed and load conditions.

Need for Voltage Tie Between Systems

The majority of our large metropolitan districts in this country are each served by systems of two or more frequencies. Where Edison systems (d-c.) are used and supplied from the a-c. systems through conversion apparatus, the early practice was in many cases to use 25-cycle a-c. power, due to the superior performance of 25-cycle synchronous converters. More recently, the tendency has been to increase the 60-cycle system in preference to the 25-cycle, because with the conversion equipment now available the advantage of the lower frequency no longer exists.

We therefore find large cities supplied by both 25- and 60-cycle systems covering the same territory, and feeding the same general load. Sooner or later it usually becomes very desirable, for best economy, to use synchronous converters of both frequencies in the same substations operating on the same d-c. bus, as shown in Fig. 9.

This has been tried in several cases, and it was found difficult to operate the 25- and 60-cycle rotary converters in parallel due to different voltage regulation on the two systems. It was also found that at times of voltage disturbance (such as short circuits) on one system, the converters on that system would invert and trip out on overspeed, with a heavy flow of current from the other a-c. system through the converters and d-c. bus to the a-c. system where the disturbance occurs. This usually results in severe burning of the brush gear and commutator of the inverted converters.

Similar experience has resulted from the parallel operation of rotary converters fed from separate isolated generating stations of the same frequency. This trouble was largely overcome by the use of suitable cable ties between the two a-c. generating stations of like frequency. These cables tend to equalize the voltage between the sources of a-c. supply and prevent the damage to rotary converters in case they invert at times of short circuit on the a-c. system.

The induction-synchronous type of frequency converter provides a tie between systems of different frequency which simulates the cable tie between stations of the same frequency as mentioned above. As explained earlier in this article, this type of set provides a voltage tie in addition to the frequency and power tie. The induction-synchronous type of set is being developed particularly for use in connection with Edison systems where it will make practical the operation of 25- and 60-cycle converters in parallel.

These systems are in many cases of very large capacity, and in order to provide a suitable link, sets of large size are necessary. Modern large city systems are using steam turbine generators of from 20,000-kw. to 50,000-kw. sizes, and it is considered good practice to use a frequency converter, for such a tie, of the same size as the largest generating units. This allows a reduction in standby generating equipment. It is not good practice to operate with a standby generating capacity of less than that of the largest generator on the system. This means that with 25- and 60-cycle systems operating separately, each using units of 35,000-kw. capacity, there should be one generator unit of this size on each system for standby service. If these two systems are tied together by a frequency converter of 35,000-kw. capacity, one standby generator for the two systems would be sufficient, since it could be used to supply load on either system in case of a generator or turbine failure.

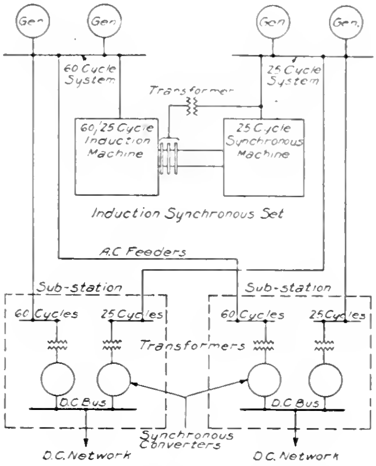

Fig. 9. Diagram Showing the Application of an Induction-synchronous Type Frequency Converter to a Typical Edison System Having Generating Systems of Both 25 and 60 Cycles

The cost of a frequency converter of this size would be approximately 50 to 60 per cent of the cost of a turbine alternator set. This of course neglects the boiler capacity and other auxiliary equipment necessary with the steam turbine.

The efficiency of a 35,000-kw. frequency converter of either the synchronous or the induction-synchronous type would be approximately 94 to 95 per cent at full load.

Many large urban systems are now spending large sums of money to obtain continuity of service on their a-c. systems, as even a very short interruption must be avoided if possible. It is preferable to take a dip in voltage at a time of trouble on the system rather than to let the voltage fall to zero and this is usually possible if the system is laid out with this in mind, making proper use of current limiting reactors. The use of an induction-synchronous frequency converter may be of considerable aid in holding up voltage on interconnected systems of different frequencies, as it forms a voltage tie between the two, and will tend to hold up voltage on one system by feeding in kv-a. from the other during periods of voltage disturbance.

The cost of an induction-synchronous type set for 60/25-cycle systems (including the transformer for the 25-cycle rotor circuit) is about the same as the cost of a synchronous set. For systems where the frequencies are more nearly the same, the size of the synchronous machine becomes smaller in proportion to the rating of the set and, therefore, the cost of such sets should be somewhat less than for a synchronous set. The induction-synchronous set involves a somewhat more complicated rotor construction than a synchronous machine.

It is possible to utilize the set as a condenser for either system during times of light load on the set. If reactive kv-a. is required on the low frequency system, simply use the synchronous unit as a condenser. If the higher frequency system requires reactive kv-a., it may be obtained through the induction machine from the synchronous unit, or from the lower frequency system. The peculiar thing about this is that you can take out from the induction machine more kv-a. than you put in. Consider a 60/25-cycle set, with the induction machine operating at 25-cycle slip. For each 25-kv-a. input to the rotor, you obtain 60-kv-a. output from the stator (neglecting impedance drop in the machine) so that it is possible to obtain considerable reactive kv-a. at 60 cycles, with a comparatively small amount taken from the 25-cycle machine or line. This flow of reactive kv-a. through the induction unit is controlled by the ratio of the transformer in the rotor circuit, or by a change of 25- or 60-cycle bus voltage. It is evident that the usefulness of the induction-synchronous type of set is nearly as great as a synchronous set as a source of synchronous condenser capacity, during times of light load on the set.

This type of set adds the voltage tie between systems, which is considered absolutely essential in certain cases, such as the problem involving parallel operation of synchronous converters of two frequencies, which was outlined above.

Frequency converters may now be obtained in practically any size required, as their design and construction involves no greater difficulties than are met in the building of any large generating equipment. Sets of 35,000-kw. capacity are now in process of construction and there is no reason why such sets should not be built of larger capacities to keep pace with the requirements of large power systems.

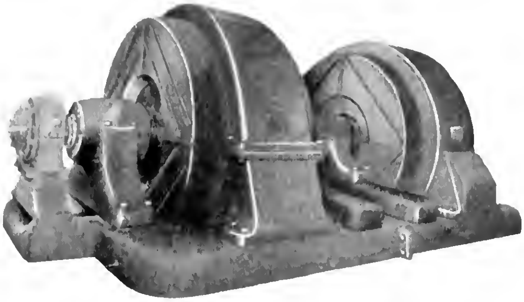

Fig. 10. A 12,000-kw. 500-r.p.m. 25/50-cycle Frequency Converter with Direct Connected Exciters and Stator Shifting Device

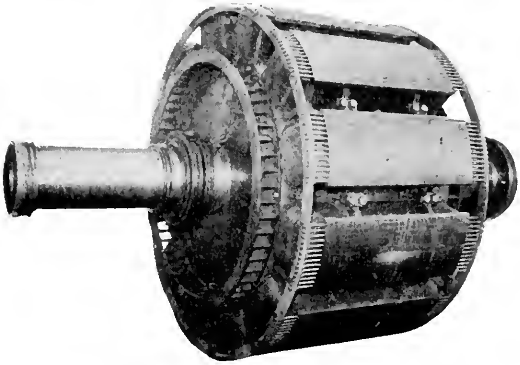

Fig. 11. Rotor of a 15,000-kv-a. 500-r.p.m. 50-cycle Generator

Mechanical Features

It is the general practice to build large sets, such as 10,000 kv-a. and above, with four bearings and to provide sheet-steel air deflectors on the machines, making them either semi or totally enclosed. Figs. 1 and 10 show the arrangement of bearings and enclosing features in common use on large synchronous sets. Figs. 11 and 12 show the rotor construction used on large synchronous machines. The simplicity and ruggedness of construction used are self-evident.

Accessories

In addition to the two main units of a frequency converter, it is often found desirable to add exciters, induction starting motors, phase (stator) shifting devices for paralleling sets, and forced oil lubricating systems for use during starting.

It is very desirable to have an individual exciter for each synchronous machine, as this allows power-factor control by exciter field rheostat, and eliminates the necessity for a main generator field rheostat. By the use of induction starting motors and high pressure lubrication of main bearings during starting, the kv-a. taken from the line for starting may be reduced to 1/3 or 1/2 that required for starting one of the synchronous machines with a starting compensator.

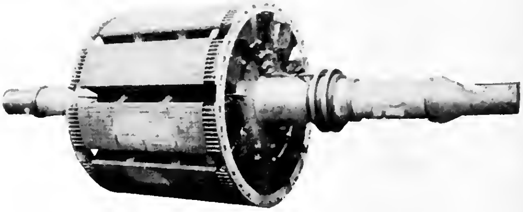

Fig. 12. Rotor of a 10,000-kv-a. 720-r.p.m. 60-cycle Generator

If one of the main units is a wound rotor induction machine it is possible to use this machine for starting the set (with a suitable resistor in the secondary circuit) and very good starting characteristics are obtained in this way.

If sets are to operate in parallel it is a great advantage to have a motor-operated phase shifting device on one machine of each set, as this allows the absolute control of load division between sets, and enables the operator to add or remove sets from the line without any sudden olts to the system (other than starting kv-a. required). This phase shifting device is especially desirable on large sets, and the cost is a comparatively small item.

Development of Automatic Control

By H. C. Hoyt

Lighting Department, General Electric Company

The author writes very interestingly on the development of automatic control for electric stations. There is a lot of information in this contribution which has not appeared in other articles on the subject. A short review of this nature will be profitable reading for many of our subscribers.—Editor.

There is possibly no more striking illustration of the emancipation of the electrical industry from purely manual operation, than in the contrast between past and present central station boiler rooms. When one recalls the inferno of the dark, narrow, coal cluttered firing aisles of a few years ago and the crews of half stripped sweating firemen who labored there in a blackness, more intensified than relieved by the glare of open furnace doors, and compares that scene with the light, well ventilated stations of today in which human labor has been all but eliminated, one can appreciate the benefits of automatic appliances.

While less spectacular in appearance, the change resulting from automatic control of substations and hydro-electric generating stations, is, in reality, far more complete. Regular shifts of operators—water tenders, oilers, etc.—are still required in even the most modern boiler room, while the automatic station normally needs only an occasional inspection for cleaning and adjustment.

Labor saving devices are always popular. Undoubtedly a number of operators had developed more or less ingenious arrangements amounting to automatic control of portions of electrical equipment for their own convenience, before the development was seriously undertaken by the manufacturers of electrical apparatus. Little record of these individual experiments is available, so that any history of the development of automatic equipment must, of necessity, be confined to published data of the larger manufacturing companies.

So far as these records go, the beginning of automatic operation is found in the Rowena Street Station of the Detroit Edison Company where, in 1912, was installed a remotely controlled automatically operated synchronous converter for serving a lighting and power load. There is little doubt that this was the first development in which the attempt at automatic control of a complete electrical unit, as distinguished from one of the various functions of this unit, was undertaken.

While this automatic equipment at Detroit proved entirely successful and was followed by additional units for the same Company, the next installation of automatic equipment in point of time, was for very different service and consisted of the automatic control for a railway type converter on the lines of the Elgin and Belvedere Railroad at Union, Ill., in 1914. This installation should perhaps be classed as the first completely automatic installation in the sense that it was started, connected to the line and shut down entirely without assistance from an operator. This equipment followed the plan, which has subsequently become almost universal practice for this service, of starting the converter on low voltage, connecting it to the line and shutting down on underload. So successful was the operation of this installation, that automatic equipment was rapidly purchased for all the other substations on the system, and shortly its application was started on the lines of the Des Moines (Iowa) City Railway Company.

The inherent advantages of the automatic equipment to railway systems, and particularly to interurban lines on which the service is rather infrequent, led to a very rapid expansion of the application to this particular class of service. Here the success of the automatic control was so well proven and the various items in this equipment so fully developed, that the expansion of this control to other types of apparatus was the natural and logical result.

In 1917 automatic control for a 3000-kv-a. synchronous condenser was installed at the Hazel Green Substation of the Interstate Light & Power Company, for the improvement of power-factor and regulation on a line serving the lead mines of this district. This equipment performed so successfully during the years of unusual activities in the lead mining industry, that it seems strange the demand for automatic control of synchronous condensers, since this initial installation, has not been greater. Inherently the control of this equipment is of the most simple type and the ability to locate condensers at the load end of transmission lines, where often there is no occasion for installation of other substation equipment requiring an attendant, would seem to make this class of service an ideal one for automatic operation.

It is believed the first hydro-electric station to start and be switched on the line, due entirely to the load requirements of the system, was the one placed in operation by the Iowa Railway Light and Power Company at Cedar Rapids, Iowa, in 1917. This equipment has been so fully described and reviewed in the technical press that mention of it only is sufficient at this time.

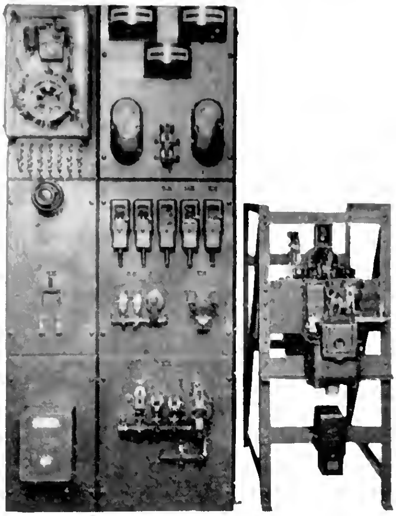

Fig. 1. Automatic Control Equipment for Waterwheel-driven Generator. The generating equipment transmits its power to a mill and is started by energizing the transmission line through the closing of a manually operated switch at the mill. Generator oil circuit breaker of the automatic solenoid operated type is shown mounted on separate channel iron framework.

The installation at Cedar Rapids was quickly followed by others for a similar class of service, notably among the earlier developments being that of the Blue River Power Company at Seward, Neb., and Station No. 2 of the Ontario (California) Power Company. An interesting feature in connection with the Blue River Development is that, so far as is known, this was the first instance in which a drop in frequency on the system was used as the indication for this station to automatically come into service.

Probably the most notable example of applying automatic control to city lighting service, is that of the Kansas City Power & Light Company. Due to a re-organization, the lighting service of the entire city was changed from a frequency of 25 to 60 cycles. This necessitated the furnishing of new conversion equipment throughout for the Edison 3-wire district in the business section of the city. It is most unusual for such a complete reconstruction of an entire Edison System to be undertaken, and before proceeding with final plans, an exhaustive study was undertaken as to the best method to adopt. It was finally decided that for reasons of economy and reliability of service, a plurality of automatic substations scattered throughout the district would best meet the requirements. A total of ten synchronous converters arranged in five substations of two units each were therefore ordered. These stations are interconnected through the Edison network and the automatic equipment is so arranged that one unit in any particular station will start in response to the load demand in its immediate neighborhood, followed by the second unit when needed.

Aside from the reliability secured through the prompt and positive operation of this automatic equipment, ability to pick up load after an entire shut-down of the Edison System is furnished by the use of water-cooled cushioning resistors which are automatically placed in series with the load so as to limit the output of each individual converter to its normal full load current, until such a time as the system voltage can be raised to approximately normal. Cushioning resistors of the air-cooled type had been used in railway service for a considerable time prior to this, but it is believed Kansas City was the first installation of water-cooled

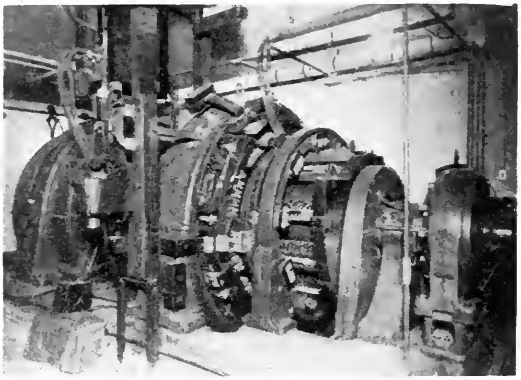

Fig. 2. Motor-generator Set Consisting of 1875-kw. 250-volt Generator, 13,200-volt Synchronous Motor, and Direct-connected Exciter for Separate Excitation of Motor and Generator Fields. Solenoid operated air circuit breaker for short circuiting generator differential field winding is shown mounted on a separate framework. The set supplies power to an Edison three-wire network.

resistors having sufficient capacity to enable the converters to function successfully under abnormal conditions up to the point where the heating of the converter required its shut-down.

Application of automatic control to motor-generator sets of both synchronous and induction types, naturally followed the successful operation of the converter and synchronous condenser equipment. Adoption of synchronous motor-generator sets especially has come into favor, not only because of the greater stability of this motor, enabling it to "hang-on" during minor fluctuations in the a-c. supply which would trip out a converter, but also because of the possibilities of power-factor correction inherent in this type of motor.

The conviction had also been reached that to facilitate picking up load on an Edison system after a complete shut-down, the presence of a certain proportion of the machine equipment, approximately one-third, in synchronous motor-generator sets would prove of great assistance. Also, the development of the differentially wound generator which accomplished the same results as the synchronous converter and load limiting resistor, has further established the value of this class of conversion apparatus.

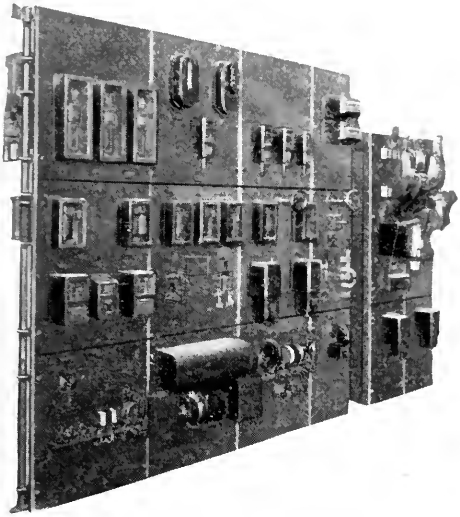

Fig. 3. Automatic Control Equipment for 1000-kw. 240-volt 2-wire Synchronous Motor-generator Set Having Differential Series Field Winding on Generator. Sequence of operation secured by motor-driven drum controller. Solenoid operated line circuit breaker and differential field short circuiting breaker are shown mounted separately.

The advantages of electrically operated reclosing circuit breakers of either the direct or alternating-current type were recognized at an early date. The development of these reclosing equipments was along the lines of solenoid operation for a number of years. This was the logical form of procedure for the direct current breakers, but for a c. operation the solenoid is inherently a far from satisfactory feature, and for that reason the motor operated oil circuit breaker, particularly in its latest form of centrifugal mechanism operated by a ¼-h.p. motor, has won a well deserved popularity.

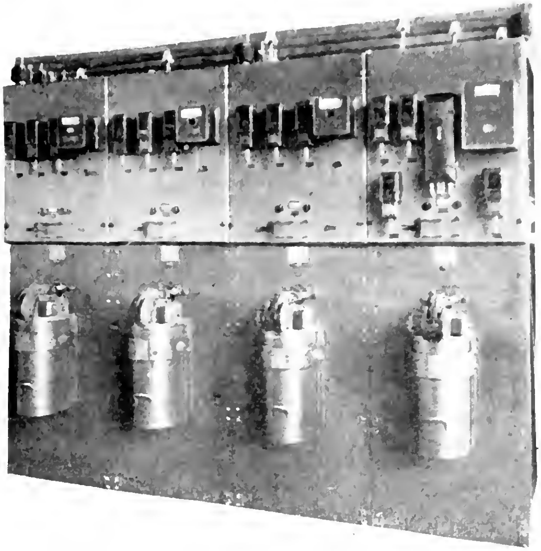

Fig. 4. Automatic Control for Alternating-current Reclosing Feeder Equipments Showing Motor Operated Oil Circuit Breaker Mechanisms Mounted on Front of Panels.

The logical development of a-c. reclosing breakers has been the complete automatic control of transformer substations; an installation offering many points of unusual interest is that of Substation "R" of the Kansas City Power & Light Company. Here, through the medium of motor operated drum controllers, this station is not only brought into service when the supply feeders from the power house are energized, but the equipment is so designed that normally one of the three step-down transformers supplying this substation first picks up the load and supplies all outgoing feeders. As the load demand increases a second transformer is automatically connected to the supply mains and serves a portion of the outgoing feeders. In case of accident, a third or spare transformer automatically comes into service and picks up the load of one of the regular units which may be temporarily disabled. So successful has this equipment proven, that additions to the present station are not only contemplated, but other stations of a similar design are now being actively considered.

The use of operation counters on various devices in the automatic equipment early became a common practice in order that some record might be kept of the performance of the equipment. In line with this custom there was developed an operation recording instrument consisting of a number of pens suspended over a clock-driven roll of paper. Each of these pens can be connected to some particular device of the automatic equipment whose operation it is desired to record. The sequence of these operations is indicated on the moving paper chart, not only as to the individual device, but the relation, in point of time, of this device to others of the automatic equipment. In this way a complete history of the operation of the equipment as a whole is made available for future study and for use in properly adjusting the various devices.

The desire on the part of operating officials for some form of supervisory control over automatic equipment in their various stations, is probably only natural in view of the importance attached to continuity in service. One of the earliest installations of a supervisory control over telephone wires for purely control purposes, was probably that installed by the Northern States Power Company of Minneapolis in their Highbridge and Stillwater Stations. A similar installation was also tried out on the lines of the Des Moines City Railway Company and its subsidiaries at practically the same date. Recently the demand for more complete information in the load despatcher's office as to the functioning of automatic equipment, led to the development of a supervisory system giving complete indication and control of the operation of all circuit breakers or auxiliary apparatus in a distant automatically operated station. One of the earliest installations of this latter system was placed in service on the lines of the Malden (Mass.) Electric Company about a year ago.

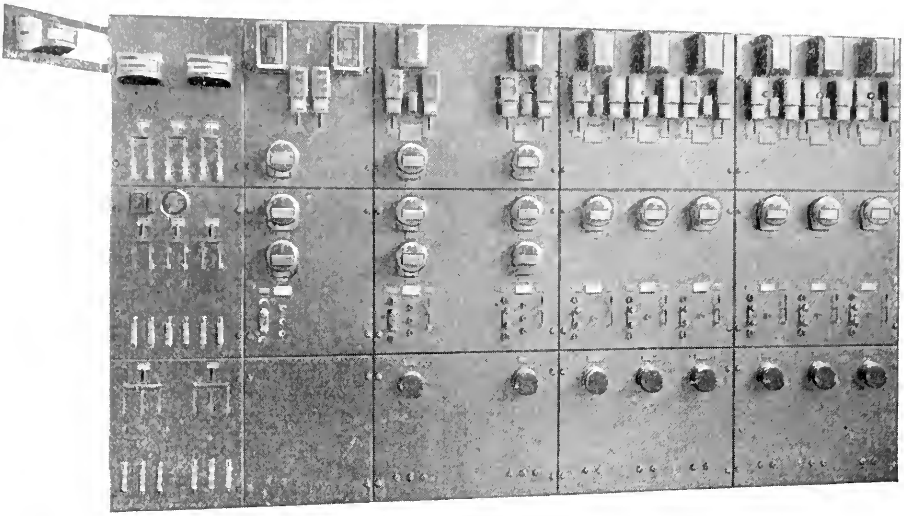

Fig. 5. Automatic Control for Alternating-current Reclosing Feeders. The equipment controls a total of 3 three-phase power circuits and 6 single-phase lighting circuits. Motor operated timing devices and interlocks are provided so that only one breaker can close at a time, thus reducing size of storage battery required. Small lever switches shown on the panels permit transfer of operation from automatic to manual control for purpose of inspection or test

Among the many items which have been developed to meet certain functions desirable in automatic control, may be mentioned the thermal relay, having heating characteristics similar to that of the apparatus which it is designed to protect and which will operate to disconnect the piece of apparatus in case danger from overheating is threatened. Flashing relays, so-called, connected between frame of a converter and ground to immediately disconnect the converter from both the a-c. and d-c. lines in case of flashover or accidental ground, have done much to render automatic control of this class of apparatus successful. There have been developed stalling relays to disconnect the apparatus from the circuit if, for any reason, the cycle of operations in starting and connecting a machine to the line is not completed. In this connection protection is also given against starting or operation of 3-phase rotating machinery under single-phase conditions. For direct-current feeders, relays have been developed which will permit "feeling out" of the line to insure its being clear from a ground or other trouble before its circuit breaker is closed.

In deciding the question of the advantages of automatic versus manual control, a great many features must be considered and individual merits of each case be accurately determined. There might be little excuse for installation of automatic control in one large Edison 3-wire station serving a territory of high load density. On the other hand, there is scarcely a case in which automatic substations could not advantageously be added to serve outlying territories supplied by either direct or alternating current.

For the central station whose business is selling electrical energy, any reduction in cost of generating or distributing this product is of the utmost importance.

For electric railways, whether urban, interurban or trunk lines, whose business is selling transportation, the cost of electrical energy is of great importance, but the raising of the average voltage, due to the more frequent spacing of automatic substations, will result in faster schedules and longer trains, both of which contribute directly to the revenue obtainable from a given amount of equipment, while decreased maintenance and repair charges and platform expense offer attractive possibilities in economy.

For industrial plants selling a manufactured product where electrical energy is but one of the items entering into the expense of manufacture, the saving in cost of this energy would probably be of far less importance than the avoidance of plant shut-down due to failure of the power supply.

It is a common idea that the advantage of automatic equipment lies solely in the saving of operators' wages. This is often the largest individual item of saving but is rarely the sole consideration.

Reliability of service in itself may often be of sufficient value to overshadow the item of operators' wages. The man who can and does think quickly and accurately in emergencies, who acts without hesitation or expensive mistakes, is too valuable an individual to be wasted on an operating job. The results of errors on the part of less skillful operators may be highly expensive.

Automatic equipment substitutes, in place of the operators usually available, the skill and reliability of the highest class of engineering talent employed in the design and functioning of automatic control.

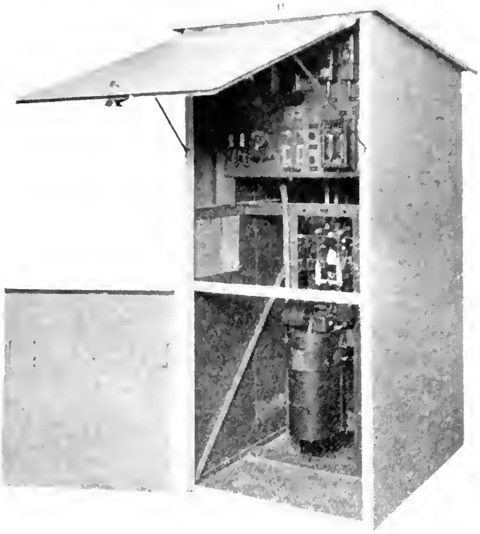

Fig. 6. Alternating-current Reclosing Feeder Equipment showing Motor Operated Oil Circuit Breaker, Mechanism, and Metering Equipment Mounted in Small Weatherproof House.

Quick restoration of service after a shutdown is an item which might well be capitalized in the good will of customers if for no more tangible reason. Automatic equipment permits the reclosing of a breaker almost instantly and operating experience has proven that the large majority of outages are caused by troubles of an instantaneous nature only. Automatic equipment, however, will permit the reclosing of breakers up to a total of three times in case the fault still exists and finally lock out the circuit until the trouble has been located and cleared.

The above are but a few of the most obvious advantages secured by using automatic control and, in general, will apply to all classes of service. Particular advantages will accrue in many individual cases. The values to be assigned such items as improved power factor and reliability of service are largely local. The considerations governing automatic hydro-electric developments are quite distinct in many respects from those covering the location of substations. But the published data available covering results obtained in actual service by automatic equipment, often over long periods of time, speak for themselves. At Cedar Rapids in one year's operation of the automatic hydro-electric station 6,580,000 kw.-hr. were generated at a total operating and maintenance charge of $42.80. The Butte Electric Railway Company operated its 500-kw. automatic converter station for three years at an average annual cost of $270.00. The Tennessee Electric Power Company has in one of its substations an automatic reclosing feeder equipment which recently functioned eleven times during an early morning storm, and so successfully that the only record of these interruptions was that shown by the operation counter installed on the breaker.

Devices for Leveling Large Machines

By N. L. Rea

Contract Service Department, General Electric Company

The "lining up" of machines has become an increasingly difficult problem with each increase in size. Machines have reached such large proportions now that special instruments have been designed to meet the requirements. The author describes these instruments and their use.—Editor.

In the early days of the industry when a 30-kw. generator was a giant and a 50-kw. required half the factory force to load on the car, the problem of erecting was simple. A spirit level, a plumb bob and a hank of silk fish line composed all the special equipment necessary. Practically all the machines were belt-driven which simplified the erecting problem.

As the size of the machines increased and direct connection became common, the spirit level had to be supplemented by straight edges. The span of the bases soon increased to such an extent that the length and cost of the straight edges became prohibitive.

We then turned to the surveyor's level, and for a time this served fairly well, but we found that the average instrument man got cold feet when we talked of sixty-fourths; and thousanths were beyond his wildest dreams. The increasing size and speed of equipment called for increased accuracy in leveling and we laid our problem before one of the best instrument makers who gave us a 22-inch engineer's, or Wye, level fitted with an especially accurate and sensitive level vial. This solved the problem as far as the instrument was concerned but left us with the standard surveyor's target.

We soon found this was not altogether suitable for our purpose and started experimenting on a satisfactory substitute. The "blind spot" back of the cross hairs is appreciable at a distance and may be several times wider than the finest mark on the target.

Some of our erectors overcame this by having two parallel lines drawn on the target, with enough space between these lines so that the cross hair would not completely cover this space. The target was used by making the cross hair lie midway between the two lines.

One of the first of these targets was made of a silver plate blackened with sulphur smoke and with two parallel lines drawn across it with a dividing engine. This plate was fastened on a regular surveyor's target with the head of an inside micrometer below it, arranged to slide the plate on the target and to measure the movement in thousandths. This arrangement was not altogether satisfactory. The lines tarnished quickly, the lacquer blurred them and caused reflection from the surface of the plate which was confusing to the instrument man.

Several other schemes were tried and through a process of elimination we developed the arrangement shown in Fig. 1.

This consists of a standard 24-inch combination square with a special target arranged to slide on the blade. The smaller bar of the target can be clamped in any position. The target proper is a sliding fit on the blade and is pulled towards the other member by a coil spring. The measuring head of an inside micrometer is mounted between the two parts and any movement of the sliding target can be read in thousandths of an inch.

The two sides of the target face are of white celluloid with three parallel lines across them. These lines are cut with a dividing engine and are blackened; they are a sixty-fourth of an inch apart. The inside edges of the celluloid are also notched between the lines as shown.

This target gives readings that check within two or three thousandths but has several disadvantages. An electric hand lamp is necessary to illuminate the target. This lamp must be carefully shaded and held so that the instrument man does not get any direct or reflected light. The light must be kept in the same relative position as a change of angle in the illumination apparently changes the reading.

In use the target and cross hairs appear somewhat as shown in the sketch in Fig. 1. For clearness; only a portion of the instrument crosshair is shown, it being superposed midway between the top and bottom lines of the left-hand set of target lines.

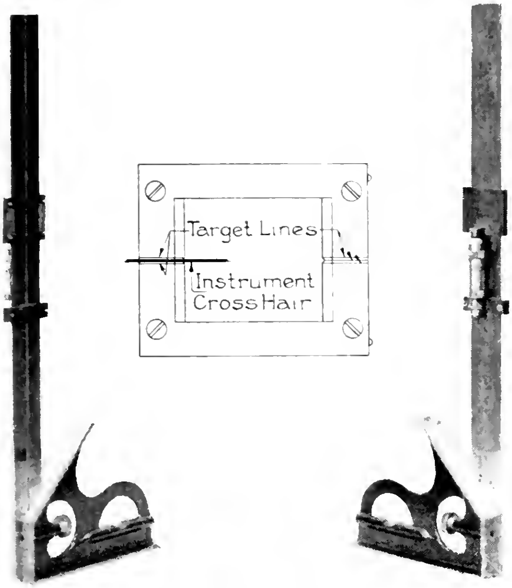

Fig. 1. Photographs of the Two Sides of a Sliding-target Leveling Device and a Sketch showing the Appearance of the Target when Viewed Through the Telescope

Lighting difficulties caused us to continue our experiments and as a result we developed the outfit shown in Fig. 2. This consists of a "V" block arranged to clamp the measuring head of an inside micrometer. The target proper consists of a steel ring arranged for mounting on the end of the measuring rod of the micrometer, any length of rod can be used to suit local conditions as we are usually interested only in the variation of height from point to point and this is read on the micrometer.

The steel ring is provided with two cross hairs of 0.003 steel wire that are at right angles to each other and 45 deg. from the axis of the measuring rod.

A sheet of white paper is held at the back of the target at the proper angle to catch the best light. This white background throws the cross hairs of both the target and Wye level in silhouette. This gives clear, sharp readings without errors from lighting changes or eye strain from reflected light.

Fig. 2. Latest Improved Form of Leveling Target for Use in Conjunction with a Telescope

The eye automatically bisects the angle of the target cross hairs with those of the instrument and a thousandth of an inch shows as an appreciable amount.

The base shown and the micrometer are standard equipment and might be varied to suit local conditions and special requirements. We have considered making the base a little longer and mounting a small round type level as a check on the staff being always plumb.

The steel ring and the cross wires are the important things in the equipment.

Development in Power Production

By O. Junggren

Consulting Engineer, Turbine Engineering Department, General Electric Company

The economical production of power is of vital concern to everyone—the kilowatt-hours generated and distributed in this country in 1922 reached the huge total of fifty billion—this figure is likely to double each five years! With such figures in mind the gain made by each increase in efficiency is apparent. The author tells us how we are obtaining better economies now than formerly and the possibilities of still further economies in future power production.—Editor.

The great expansion in power production during the past year promises to be exceeded in 1923 and 1924. This expansion has created a demand for turbine units of larger individual capacity. A company that only a year or two ago considered a 10,000-kw. unit the largest that could efficiently be utilized, now finds that 15,000 kw. is the proper size, and those previously using 20,000-kw. units are now installing 30,000-kw. units. Large systems are installing 50,000- and 60,000-kw. units. This tendency is only one example of how rapidly the power business is growing.

In planning new stations great attention is given to securing the highest economy compatible with reliable design and reasonable first cost. These studies include a careful analysis of the number of heat units required to deliver a kilowatt to the switchboard with various types and arrangements of apparatus. How effective the various arrangements proposed will be in practice, of course, cannot be accurately predicted. The conditions under which the stations are to operate vary considerably and those operating most continuously will always have an advantage in the economical production of power, but it is safe to say that the changes incorporated in the new stations will lead to material improvements in economy, and without doubt a kilowatt will be produced in these stations for less coal than in any station now in operation.

The use of steam for converting heat into power has been considered wasteful in comparison with gas engines, but for large capacities the probability that the steam cycle will be superseded is far removed. However, it is well recognized that the steam cycle has inherently theoretical possibilities closely approaching the efficiency of oil or gas engines when worked to its limit. What this limit is in practice will depend greatly upon the ingenuity of handling materials already developed and possibly upon future research work.

It is only a few years ago that the steam pressure was 150 lb., from this there has been a steady rise to 200 lb., 250 lb., 300 lb. A considerable number of new stations are being planned for 350 lb. pressure with superheat to bring the total temperature of the steam to about 700 deg. F. At the present time there are three large stations, for which steam conditions of 550-lb. gauge with superheat giving a total temperature of 725 to 750 deg. F. have been selected. The steam will be reheated up to the original temperature after it has gone through a portion of the turbine, thereby adding a considerable amount of heat to each pound of steam. At the present time 300,000 kw. capacity to be operated under these steam conditions is under contract, 200,000 kw. of which is on order with the General Electric Company.

Due to the great expansion of power companies in general and various interconnections of transmission lines, there has recently developed a demand for a special type of turbine which has been termed "Base Load Machine." As the name implies, the machine is to carry continuously a certain portion of the load, and the stations in the outlying districts of the systems are to take care of the load variations. It is obvious that with base load machines high economy is exceedingly important. Such machines are designed with only one governing valve, as they are intended to run as nearly as possible at full capacity. The governor, so to speak, will only be used as an emergency device to check the speed of the machine in case the load is suddenly removed. For emergency operation, to take care of drop in steam pressure or loss of vacuum, a hand operated by-pass is provided.

We may in the near future see large central stations located at the most favorable points for coal and water as well as distribution. These stations will supply other companies with power, such companies themselves producing power in large quantities, and these stations will be designed with the object of obtaining a kilowatt for the lowest number of heat units.

New stations are being designed with much greater attention to details than formerly, in order to obtain high efficiency as well as greater reliability. We all realize that these two conditions must go together.

Stations that are now being projected are a distinct advance upon anything that has heretofore been done and will undoubtedly produce a kilowatt with a considerable saving in coal. The Operating Company is vitally interested in how much coal it is necessary to burn to produce a kilowatt at the switchboard, but as the turbine is only one part of the operation, it is of course necessary to give as much attention to all the apparatus as to the turbine itself. If one per cent unnecessary loss has taken place in the boiler, in the piping or in the auxiliaries, it is just as important as if this per cent were lost in the turbine. We who manufacture turbines are continuously studying our end of it in order to produce high efficiency in the turbine and the generator. However, in the turbine itself we have not very much farther to go, that is, any material improvement in economy, in all probability, will not come from any radical changes or improvements in the turbine. Therefore, the advancement must be in the conditions under which the turbine operates, also improvements of all the other apparatus in the station and especially in the steam cycle so that the working range is increased. It is in this direction that much progress is possible before the ultimate is reached.

Stations now being planned have a number of new features all tending to improve the economy as follows:

First: Higher steam pressure and temperature, thereby increasing the temperature range so that we, so to speak, are starting at a higher level; the lower level is fixed by the condensing water.

Second: Reheating. This arrangement is to take the steam out of the turbine after it has done a certain amount of work, send it through a superheater, thereby adding more heat to it, and then finally expand it through the lower portion of the machine, or a separate turbine, down to the condenser pressure. The idea back of this arrangement is to put as many B.t.u.'s as possible into each pound of steam, thereby reducing the quantity of steam per kilowatt, which also reduces the quantity which must be condensed. In addition, it has the advantage of delaying the dew point in the turbine quite considerably, thereby improving the efficiency, as the efficiency of the turbine is quite sensitive to moisture. The reason for this is that it requires work to accelerate the moisture in the steam to the high steam velocity that is required in turbines. This work must be furnished by the steam itself.

Third: Bleeding for heating feed water.

It has long been known that extracting steam from the main unit for heating the feed water after the steam has gone through a certain portion of the machine will improve the station economy, but it is only recently that this plan has been extensively adopted. The main advantage is the reduction in the quantity of heat rejected to the condenser, and the more this loss can be reduced the higher the efficiency will be, other conditions being the same.

The difference between the steam going through the throttle and the steam discharged into the condenser represents what is absorbed in the feed water, and the greater this difference is the higher the economy. Theoretically, there should be a number of these extraction points, that is, in the extreme case one for each stage. This would lead to too great mechanical complication and we have provided only three extraction points in our large units. The theoretical requirement for high efficiency with extraction is that the water be heated up to the saturated temperature of the steam. This suggests the use of air preheaters for the boilers, that is, heating the incoming air to the boilers by the stack gases. It is probable that in the near future considerable advancement in this direction will be made, and when so made the minimum amount of heat will be rejected to the condenser, and thereby still greater benefit will be obtained from bleeding.

Fourth: The use of motor-driven auxiliaries.

It is only a comparatively short time ago that station operators considered it essential for safe operation to have practically all of the auxiliary apparatus steam driven, using high pressure steam with very little consideration to economy. In some cases, there was practically no drop in temperature between the steam going in at one end and coming out of such auxiliary turbines. The exhaust steam from such apparatus was either used to heat the feed water or was put back into the main unit. It is obvious that this was very wasteful. Many of these auxiliaries are now driven by motors with power from the main unit. It is probable that in the near future nearly all the auxiliaries will be driven electrically with two-fold gain in economy: First, higher economy of the auxiliary itself; second, greater extraction from the main unit.

One arrangement that has been proposed is to attach a separate low voltage alternator of suitable size to the main unit as a source of power for the auxiliaries. This arrangement, no doubt, has considerable advantage in comparison with taking power from the main busbars or from separate units called house turbines.

All the above mentioned arrangements are for new stations where the selection of the units can be made to conform to all the requirements, but there are numerous places where this cannot be done, and for such cases it has been proposed to install a high pressure boiler, using a special turbine, which, in turn, discharges the steam into the present steam mains and thence to the turbines, thereby obtaining an increased economy and increased output, without scrapping all existing apparatus. For such conditions we have proposed a standard boiler of a capacity of approximately 110,000 lb. per hour, and a turbine generator set for each boiler, the turbine acting simply as a pressure reducing valve which develops power. Such units are actually being built by us to utilize steam pressure of 1000 lb. to 1200 lb. maximum, with superheat giving a total temperature of 700 to 750 deg. F. in one station, the steam being discharged into existing mains at about 250 lb., and in another at about 350 lb. We anticipate considerable gain in economy with this arrangement, although the economy can never be as great as when the whole station is designed for high temperature and high pressure conditions.

With the increase in temperatures, the design must properly provide for the free expansion of the parts that come in contact with the high pressure steam, otherwise distortions take place which interfere with the safe operation of the unit. In new designs a most careful study has been made of this problem, in order to provide turbines perfectly safe to operate at the present temperatures and also higher temperatures in case they are called upon to do so.

Special attention has been given to the design of high pressure steam joints, particularly to the joints of the turbine shell to minimize all steam leaks, and bolts are made of high grade, heat treated steel. It is, however, practically impossible to design steam joints which can withstand the strains caused by water coming into the turbine, especially at the high temperatures now used; and, therefore, special care should be given to the design of the steam mains, and also to the operation of the boilers.

The material used in the diaphragms and turbine casings of our large turbines is steel. Even in the low pressure end where cast iron could safely be used, steel has been adopted in order to avoid additional bolting and chances of leakage. The only principal part of the turbine where cast iron is now used is the exhaust casing. By properly attaching the steel shell to the exhaust hood, the strains are materially reduced.

A number of surface air coolers are now under construction for use with turbine generators. These coolers will maintain clean generators inasmuch as they operate on a closed system, using the air over and over again. In addition, they give the advantage of reduced fire risks, on account of the limited amount of oxygen in the cooling system. Where the vacuum is sufficiently low the condensate may be used to cool the air, thereby recovering the major part of the generator loss.

Some stations are arranged to heat the incoming air to the boilers by extracting steam from the main unit. This arrangement acts exactly as heating the feed water by extracted steam and tends to increase the efficiency of the main units and reduces the heat discharged to the condenser.

Another very important point in the economic production of power is the utilization of the by-products in the coal before burning the coal in the furnace. Economic conditions in the near future may be such that this question must be given serious consideration.

The above is a short description of the present tendencies in the design of power stations. It would be natural for you to ask what possibilities there are in still further reducing the amount of coal necessary to produce a kilowatt.

Some years ago in discussing this subject with a well known engineer, it was stated that a kilowatt could be produced for as low as 12,000 heat units, and it is perfectly within the range of possibilities that even this figure may be bettered. At the time of making this statement we were very far away from the realization of such economy, much farther that we are today, but I still think that this figure can be obtained in practice. In order to obtain such results, it may be necessary to increase the steam pressure from 550 lb. to 1200 lb., or perhaps higher. The possible gain in economy by raising the pressure from 550 lb. to 1200 lb., keeping the initial temperature constant, is 10 per cent with extraction, and 7 per cent without extraction.

When the high pressure portion of the turbine is separate from the low pressure portion, high steam pressures in turbines can safely be used, as the parts exposed to the high pressure are small. Further advancement of course will be dependent upon actual trial of the forward steps being taken at the present time, but it is certain that these developments, radical as they are, will only lead to still further developments in the economic production of power.

The High Capacity Current Interrupting Testing Station of the General Electric Company

By C. E. Merris
Switchboard Engineering Department, General Electric Company

Until the last year or two the development of oil circuit breakers to keep pace with the ever-increasing generator capacity of large systems had been hindered by the lack of satisfactory testing facilities of sufficient magnitude. The testing station described in this article was built to remove this handicap and has already demonstrated its worth.—Editor.

A comprehensive program for investigating the behavior of current interrupting apparatus under various conditions has resulted in the erection of a thoroughly modern and unique testing station at Schenectady with all equipment necessary to test to destruction high interrupting capacity apparatus.

This station has been in operation approximately one and one half years and already has given answer to many problems that could have been solved in no other way. The result has been the improvement in several forms of interrupting devices, either by a change in construction or the addition of some new means to improve the behavior of the individual device when subjected to interrupting duty. For example, the value of the separating chambers with the latest type of baffle as used in the type H breaker, and the explosion chamber in the tank type breakers, has been proved conclusively by means of this testing plant.

As short circuits or dangerous overloads on power lines cannot be entirely avoided there must be means provided to remove them quickly from the system. Whether the removal is done safely or disastrously depends largely upon the operation of the oil circuit breaker.

Due to the many variable problems involved, the building of a dependable oil circuit breaker is inherently difficult. However, it is not now so baffling a problem as it was before the testing equipment herein described was available in a specially designed station where many factors could be kept constant during the investigation of one variable.

Inside the oil vessel actions take place which can not be observed and which for a long time could not be measured. Thus, the path taken by the arc, the general form of the gas "bubble," the length of the arc under various conditions, the pressures generated, the speed of the moving parts at all stages of the stroke, the proper oil level, the scientific venting of the gas to prevent oil throwing and many other phenomena were practically unknown or very insufficiently investigated. The solution of these problems depended very largely on finding out certain empirical data which could be obtained only by a large number of tests under a given set of conditions on a system large enough to stress high capacity breakers to failure. At the same time, this system had to be flexible so that the conditions were under control, thereby permitting the change of one variable at a time.

Handicaps to Testing

Heretofore high capacity short circuits could be obtained only on the systems of large power or central station companies. The progress of testing breakers on these lines was slow and somewhat uncertain for the following reasons:

Short circuits on commercial systems which would stress the larger breakers to their capacity were believed to be hazardous to equipment and very objectionable to customers having synchronous apparatus which would very often be thrown out of step during short circuit tests.

There was great expense involved in sending apparatus, instruments, operators, and engineers to distant cities where they might have to remain for months awaiting favorable opportunities to make

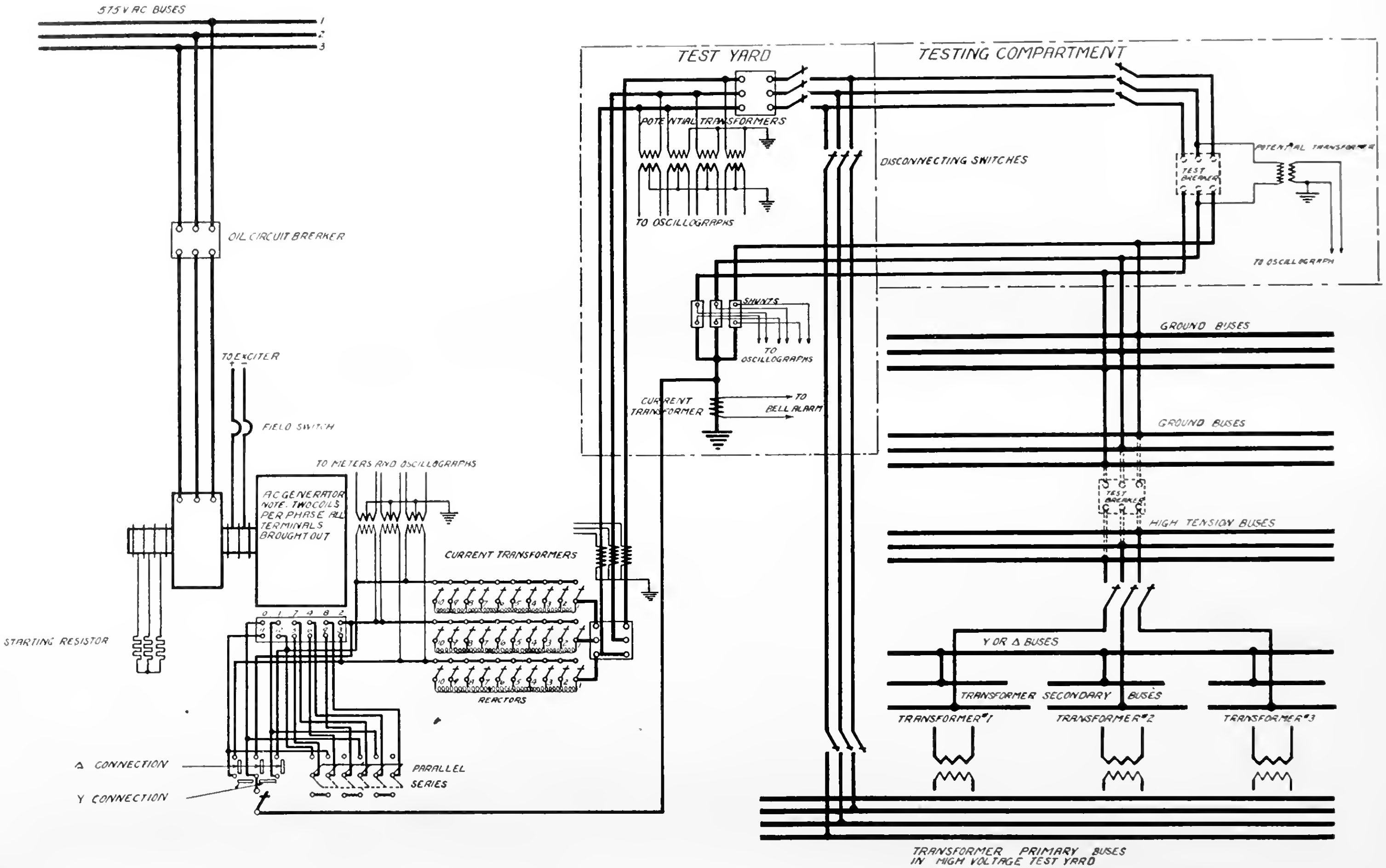

Fig. 1. Diagram Showing the Essential Features in the System of Connections Used in the Testing Station

tests at such times as suited the convenience of the power or central station company.

There was almost an entire lack of control of conditions of voltage, current, power-factor, etc.

Progress was slow in the cut and try method of investigating samples built to incorporate improvements indicated as desirable from the preceding tests. Oftentimes conditions changed so that the power companies could not permit succeeding tests for a year or two and sometimes they were averse to having any further short circuit tests made at all. This delay often detracted greatly from the value of the data obtained and greatly impeded progressive development.

Evidently a high capacity testing station was the only satisfactory means by which existing problems could be solved and pace kept with future development. Accordingly a 26.700-kv-a. station was built and devoted exclusively to interrupting capacity tests.

Station Apparatus

A specially built alternator (26,700 kv-a., 300 r.p.m., 25 cycles, 13.200 7620 6600 3810 volts with two coils per phase and all coil terminals brought out to convenient switches) feeds power through two large capacity oil circuit breakers to a "bomb-proof" testing compartment in which the test breaker is set up. One breaker acts as a generator protective breaker while the other is used as a closing switch to energize the bus leading into the testing compartment. In a high voltage testing yard, equipment has been installed adjoining the "bomb-proof" so that by throwing disconnecting switches three high voltage transformers can be energized and made available for testing. Four oscillographs, with an adjoining developing room, form part of the permanent station equipment. Other oscillographs may be readily connected when desired. A diagram of the connections of the station is shown in Fig. 1.

A 3-phase 16-pole 1500-h.p. 300-r.p.m. 550-volt induction motor, coupled directly to the alternator shaft, is connected through a 15,000-volt oil circuit breaker to an open delta transformer bank, 12.000 550 volts, which is connected through another oil circuit breaker to the 12.000-volt distribution bus of the works.

In the motor lines are two current transformers to operate inverse time limit overload relays with comparatively long time delay settings. These are provided for emergency short circuit protection and function to trip the breaker in the event of heavy sustained overloads in the motor winding.

The motor is started by means of a group of grid resistors and large contactors. Accelerating, or lock-out, relays on the contactor coils make the outfit "fool-proof" and yet the motor can be run below full speed if desired by stopping the controller handle at any one of the six different notches.

In the exciter set a direct-current 6-pole 150-kw. 1200-r.p.m. 250 235-volt compound-wound generator is direct connected to a 225-h.p. 1200-r.p.m. 550-volt induction motor connected through a 15.000-volt oil circuit breaker to the 12,000 550-volt transformers.

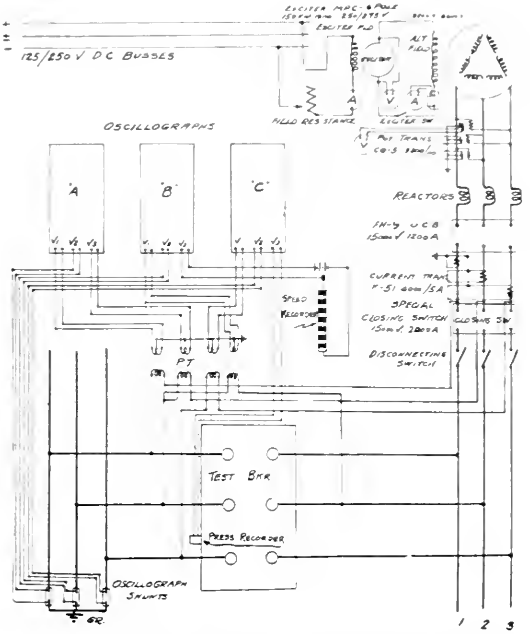

Fig. 2. Diagram Showing System of Connections for a Three-phase Test Employing Three Oscillographs

The exciter armature is connected through a solenoid operated field switch to the alternator field. Field discharge resistance is provided in parallel with this field switch. Grid resistors located in the pit beneath the alternator, for use in series with the alternator field, are connected to a contactor on a control panel and are readily available when desired. Forced lubrication and water cooling systems are provided for the alternator bearings.

Generator

The 26.700-kv-a. 25-cycle alternator is especially braced both in the frame and the windings to withstand the enormous strains thrown upon it. The rotor, including the motor rotating parts, weighs approximately 150 tons. This gives a flywheel effect of approximately (WR^2) 3.000.000 lb. ft.

Two coils per phase with all terminals brought out to convenient disconnecting switches afford a combination of series, multiple, Y or delta connections whereby four test bus voltages at full excitation are available; viz., 13,200, 7620, 6600, and 3810.

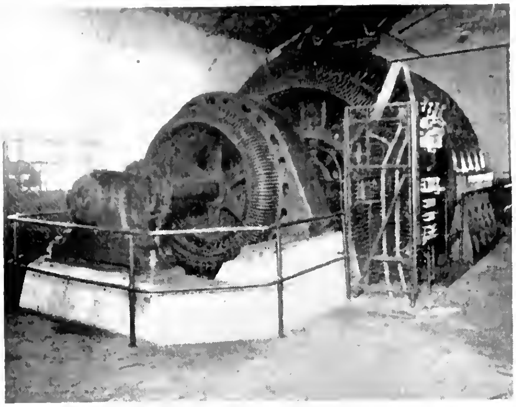

Fig. 3. Testing Generator, 26,700-kv-a., 300 r.p.m., 25 Cycles 13,200/7620/6600/3810 Volts

Reactors

Between the generator coil switches just referred to and the protective 15,000-volt 2000-amp. oil circuit breaker is a set of reactors, two in series per line, with taps brought out to another set of disconnecting switches. There are nine taps per pair of reactors affording reactance steps at intervals between 0 and 6.1 ohms.

Current Measurement

Current is measured by oscillographs connected to special shunts located in the test bus just ahead of the point of grounding. In order to get these shunts near the oscillograph, which are of necessity located in the control room, the test bus is carried back from the "bomb-proof," through the shunts and grounded. Approximately 40 ft. of twisted pair leads are required to run from each shunt to its corresponding oscillograph. The shunts are arranged so that their axes lie in the planes of an imaginary cube, *i.e.*, with the three axes mutually at right angles. This arrangement practically eliminates errors due to inductive effects of one shunt upon another. Shunts are used because they are considered more accurate than current transformers for recording transient phenomena.

Voltage Measurements

Generally, voltage is measured by the use of potential transformers connected in the circuit at the desired points. Twisted pair leads run to the oscillograph tables.

In some cases where transient phenomena are being studied closely it has been found desirable to use high resistances, across a small portion of which an oscillograph shunt is connected to give a potentiometer effect. Sphere gaps are used in some classes of investigations where high voltage impulses are expected.

Pressure in Test Breaker

Special apparatus has been developed to record the pressure at all times during the drawing of the arc in the test breaker. This recording device is very sensitive to rapid changes in pressure and has proven extremely valuable in studying the phenomena taking place inside the breaker.

Speed of Test Breaker

The speed recorder used has proved very valuable in studying the performance of breakers in action.

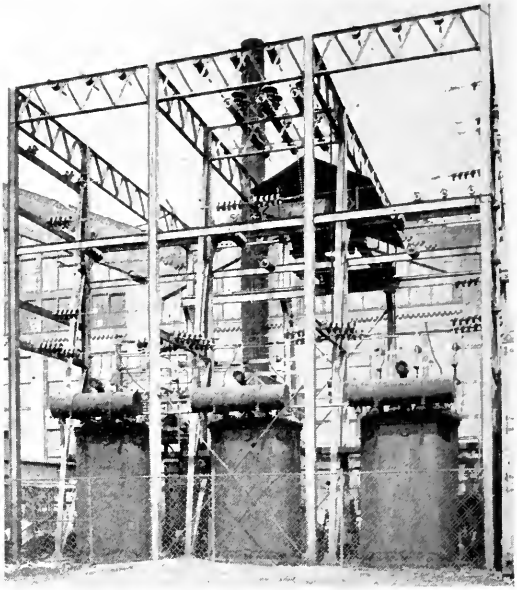

Fig. 4. High Voltage Equipment of Testing Station

Control

With the driving motor and exciter set running, the control of the protective breaker, closing breaker, exciter field, alternator field, and test breaker is centered at the control board in the operating room. Furthermore, by tripping the direct-current control breakers at the control board all oil circuit breakers in the station can be tripped out in an emergency. Several interlocks are provided to insure the proper sequence of operation of the important breakers in the event of failure of one control circuit. Thousands of short circuits have been interrupted with no instance of the protective breaker failing to clear the trouble.

The short circuit is actually thrown on by closing a knife switch on the oscillographer's table. Thus there is close coördination between the opening of the shutters and the operation of the test breaker. With the skilled operators employed, it is seldom indeed that an oscillographic record is missed.

Cars

Steel cars are provided on which the test breakers are mounted, adjusted, run into the "bomb-proof" for test, and then returned to the assembly floor. This arrangement permits the crew to get the breaker ready during the time that its predecessor is actually being tested.

Fig. 5. Test Breaker Ready to be put into Testing Compartment

Oil Handling Equipment

Storage tanks for both new and used oil, together with a pumping and filtering system, are being installed. This equipment will permit the rapid handling of oil and assure proper dielectric strength.

Power Available

There are not many power systems in the country which have an available capacity under short circuit conditions exceeding 600,000 kv-a. at 13,200 volts. This is equivalent to 200,000 kv-a. at 7630 volts per phase on a Y-connected grounded system which is the connection ordinarily in use. The short circuit capacity of the generator in the testing station considerably exceeds this capacity so that breakers at that voltage can be tested at their full rated interrupting capacity. If the breaker is of a type that permits of testing its breaks individually, then by testing a single break a capacity much in excess of 200,000 kv-a. per phase can be obtained.

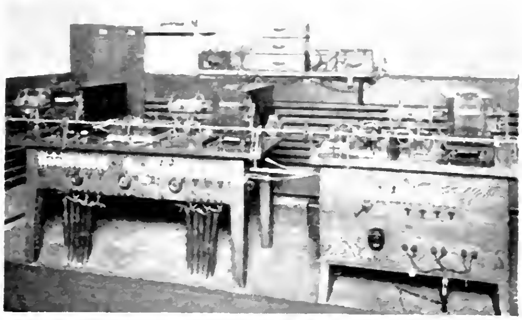

Fig. 6. Three Oscillographs on one Driving Shaft Used in the Control Room

Conclusion

During its comparatively brief existence, the high capacity testing station has developed considerably beyond the original plans. It very soon became apparent that such an equipment was vital to the design of dependable oil circuit breakers and other circuit interrupting devices. The old order of things was no longer adequate. Advanced designs of generating, transmitting, and converting apparatus of super-power systems representing millions of dollars in investments had to be guarded by scientifically designed breakers. The data had to be obtained. This testing station is producing it. By close co-ordination of the testing, designing and factory organizations, very superior breakers scientifically constructed are being built and will continue to be developed —superpower breakers for superpower systems.

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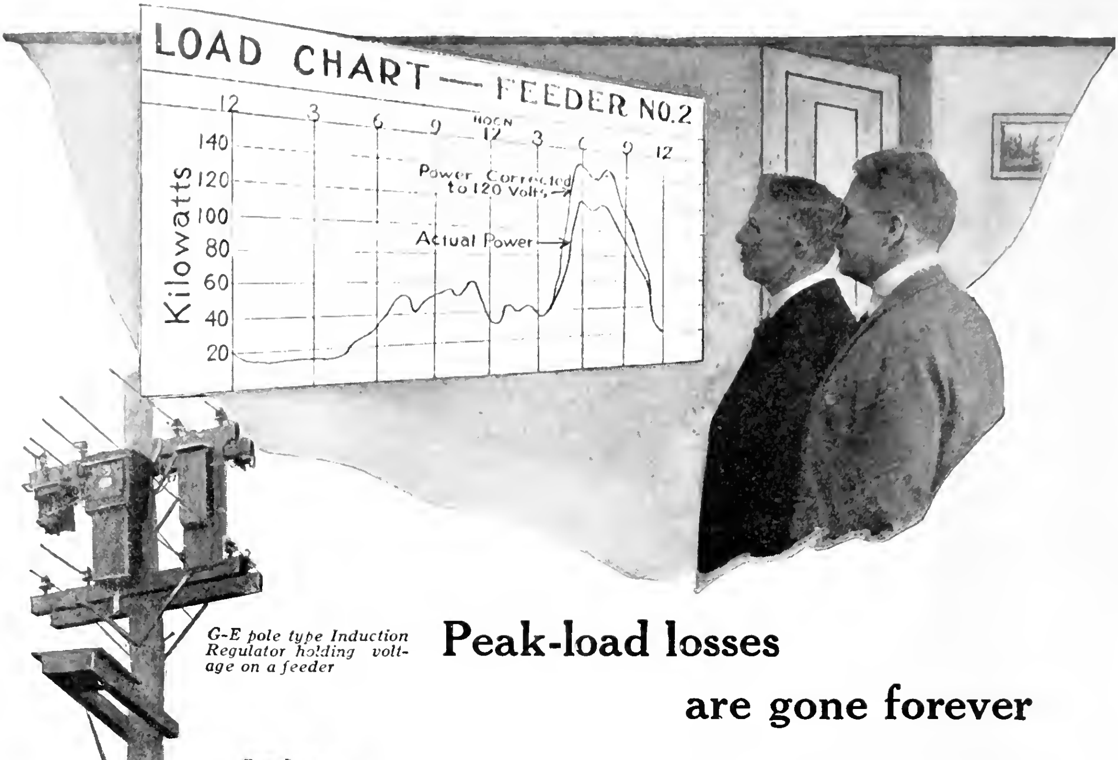

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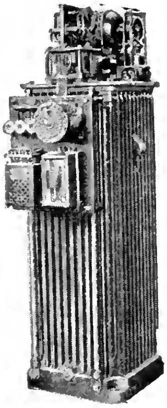

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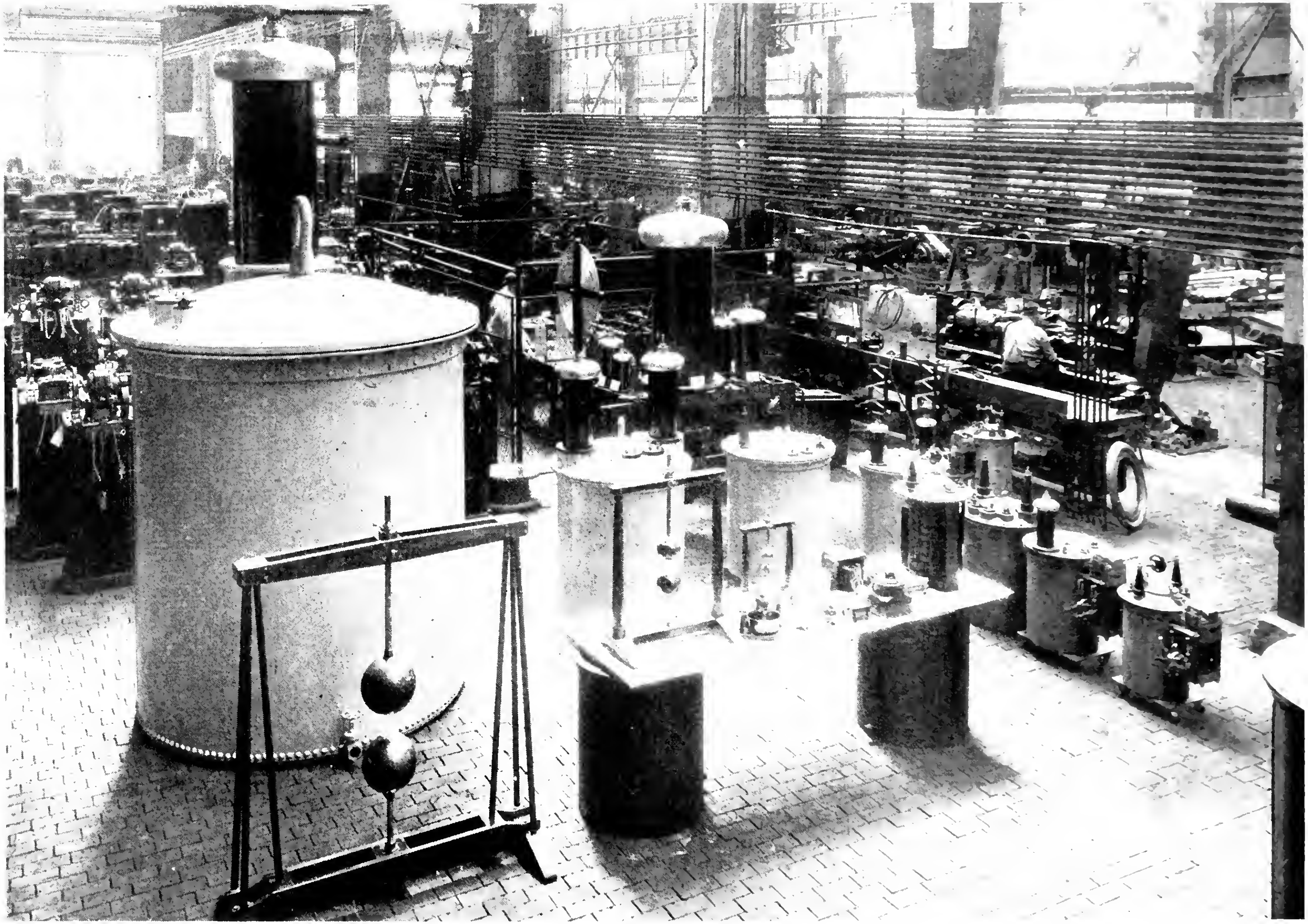

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REVIEW

COFFIN FOUNDATION AWARDS

In our January issue of this year we announced the founding of the Charles A. Coffin Foundation—and on this occasion we have the pleasure of announcing the first award. It should be recalled that this Foundation was established as an expression of appreciation of Mr. Coffin's great work, not only for the General Electric Company, but for the entire electrical industry.

The first award was made to the Southern California Edison Company in recognition of its notable contribution during 1922 to the development of the electric light and power industry in its territory.

The award was presented on the evening of June 7th at the Public Policy meeting of the National Electric Light Association and was received on behalf of the Southern California Edison Company by Mr. J. B. Miller, President of the Company. The certificate of award bears the following inscription:

Charles A. Coffin Foundation
Established by
GENERAL ELECTRIC COMPANY
For the advancement of the Electrical Art
Awards
THE CHARLES A. COFFIN MEDAL
To the
SOUTHERN CALIFORNIA EDISON COMPANY
CALIFORNIA
In recognition of its distinguished contribution to the
development of electric light and power for the
convenience of the public and the benefit of the industry during the year 1922.

After the certificate of award had been presented a check for $1000 was handed to Mr. Miller to be turned over to the employees' benefit or similar fund.

Finally, a beautiful gold medal which had been struck for the occasion was presented to the Southern California Edison Company. This medal is a striking piece of work—on the obverse side appears a portrait of the man whose name and work it was sought to perpetuate with the inscription Charles A. Coffin Medal 1923, and on the reverse side the following is inscribed:

> "For distinguished contribution to the development of electric light and power for the convenience of the public and the benefit of the industry—awarded to the Southern California Edison Company, California, 1922."

We reproduce the obverse side of this medal as the cover of our magazine this month.

The presentation was made by Frank W. Smith, President of the National Electric Light Association and Chairman of the Charles A. Coffin Prize Committee. The other members of this committee are Martin J. Insull and Dr. S. W. Stratton.

The committee reports that 18 companies responded to the invitation to submit presentations of their accomplishments and that it was no easy task to come to an unanimous opinion as honorary mention might well be accorded several of the splendid presentations.

The following day, June 8th, the Charles A. Coffin Fellowship and Research Committee, consisting of Dr. Frank B. Jewett, Dr. Charles F. Scott and Dr. John C. Merriam, announced the award of seven fellowships, totalling $5000. These awards went to Edwin Lawrence Rose, of Pasadena, Cal.; Ralph A. Beebe, of Monson, Mass.; George Lynn, of Lawrence, Kansas; William L. Fink, of Detroit; Elmer V. Hutchinson, of Cleveland, Ohio; Henry N. Beets, of Grand Rapids, Mich.; and Alfred Leonard Dixon, Champaign, Ill. All the recipients are college graduates engaged in research work and are planning research work in the fields of electricity, physics and physical chemistry.

The Electrical Plant of Transocean Radio Telegraphy

By E. F. W. Alexanderson, A. E. Reoch and C. H. Taylor
All of the Radio Corporation of America

Radio experts and amateurs alike will be interested in this instructive paper which gives an account of the equipment and of the methods used by the Radio Corporation of America in its transoceanic radio business. This paper is to be read at the midsummer convention of the A.I.E.E. which is held this year at Swampscott, Mass., June 26 to June 29.—Editor.

At the beginning of 1920 the United States Government removed the war restriction on commercial radio service, and the Navy Department restored to the Radio Corporation of America those stations which were built and equipped in 1914 by the Marconi Wireless Telegraph Company of America for transocean service.

In addition to the agreements previously entered into with countries in Europe for transocean radio service, the Corporation faced the situation arising out of the Great War, in which practically every European country demanded direct radio communication with the United States.

The need for the provision of modern facilities for carrying on radio communication with those countries with which agreements had already been made, was imperative, and hardly less imperative was the need for the expansion of our facilities to meet the new situation.

The radio equipment in all of the installations restored to the Corporation was of obsolete type and based on the use of damped waves, except in the case of the New Brunswick station. At that station the Navy Department had instructed the General Electric Company to install high-frequency alternator equipment and to modify the antenna circuit to meet the requirements of their system. Accordingly, an alternator equipment was installed which was able to supply to the antenna circuit 200 kilowatts at the high frequency to which the antenna circuit is tuned. The antenna at this station had been erected as an inverted L, approximately a mile long and 550 feet wide. This was changed to the multiple-tuned type by adding five tuned down leads, equally spaced along the length of the antenna, and connecting them through a balanced distribution system to the ground and counterpoise wires. This installation has been described by technical papers read in 1920 and 1921.

Operation of the system of the Radio Corporation started with two transmitting stations—at New Brunswick, New Jersey, and at Marion, Massachusetts. Each of these transmitting stations had its corresponding receiving station at Belmar, New Jersey, and at Chatham, Massachusetts, respectively. New Brunswick was used for communication with England, and Marion for communication with Norway. The telegraphic operation of the English circuit was centered in Belmar, and the operation of the Norwegian circuit was centered in Chatham. Messages to England or Norway were telegraphed to Belmar and Chatham respectively, where they were copied and transmitted over the radio circuit via New Brunswick and Marion. Similarly, messages from England and Norway were received in Belmar or Chatham, were copied by hand, and re-telegraphed to New York. This process involved several relays of telegraph operators with the consequent high expense and possible delays and errors.

With the present system of operation, the Radio Corporation has six transmitters on the Atlantic coast, two in Tuckerton, one in New Brunswick, one in Marion, and two in the Radio Central station on Long Island. All these transmitters are controlled directly from the traffic office in New York City.

Only one receiving station is needed for all incoming messages. This receiving station is located at Riverhead, Long Island. It has a single antenna of a new and special type, which will be described later. This antenna intercepts the waves from all European transmitting stations. The receiving apparatus, also of a new type, separates this conglomeration of ether waves which come in over the receiving antenna, into separate messages which are automatically relayed over telephone wires so that all messages are received and copied in the same traffic office in New York.

The transmitting station on Long Island—known as "Radio Central"—and the receiving station at Riverhead, Long Island, represent the modern system of the Radio Corporation. The stations at New Brunswick, Marion, and Tuckerton are adaptations of the modern transmitting apparatus developed by the General Electric Company and antennas built before the war. The characteristic features of the transmitting system are: The high-frequency alternator, the multiple-tuned antenna, the speed or wavelength regulator, and the magnetic amplifier.

In the Riverhead receiving station the method of centralization has been carried to its logical conclusion by concentration of all radio apparatus in the one station, and concentration of all reception in New York. The advantage of such concentration is obvious. New receiving circuits for communication with any new station in Europe can be added at a negligible cost by installing a new set of receiving apparatus on some of the shelves provided for that purpose in the Riverhead receiving station.

The Radio Central transmitting station has been planned in such a way that the cost of additional transmitting units will be a minimum. The choice of the site of the Radio Central transmitting station was carefully considered, looking forward to a growth of international radio communication which would require as much as twelve transmitters in this new station. Two of these twelve transmitters are already completed.

The principal considerations in selecting the site for the Radio Central station were:

1. The site must be within a reasonable distance from New York—the center of traffic.
2. A large tract of land of a desirable nature must be available, at a moderate cost.
3. A good power supply must be within easy reach.
4. There must be direct and reliable wire line communication with New York City.

The site selected on Long Island fulfilled these requirements in an ideal way, but another desideratum which, in the past, had been the deciding factor in selecting sites for transmitting stations, was not fulfilled in the Long Island location—a natural low ground resistance. The Long Island ground consists of quartz sand of extraordinarily high resistance. The decision, therefore, regarding the selection of this site was a grave responsibility for the engineers of the Radio Corporation. It meant a radical departure from the generally accepted theories. It implied that practical operation rather than technical considerations was to be the controlling factor. The engineers thus undertook to remedy by new developments in the technique what nature had failed to provide—a good ground. Much progress had already been made to reduce ground resistance by multiple tuning and ground equalizers, but this experience had been gained in stations like New Brunswick, Marion, and Tuckerton, where the natural ground resistance was low. However, we had sufficient faith in the further possibilities of development of improved grounding methods to take the responsibility for starting the construction of the new station while investigation was going on to find a solution for the grounding problem. The development work of the new ground system required as much time as the completion of the rest of the station, but by the time the station was ready to go into service the ground system was also ready and proved to be successful beyond the most sanguine expectations.

The Radio Central transmitting station of the Radio Corporation of America is the first of our stations that has been planned and designed from the beginning to meet modern requirements, the other stations having been made to conform to modern practice by modification of equipment installed in earlier times. The Radio Central type of station is being duplicated in Poland and Sweden. This station has been frequently described and while its 400 ft. steel towers with 150 ft. cross arms are quite well known, little has been published regarding the technical performance of the plant.

Radiation

The transmission value of the transmitting station is expressed by the product of the effective height—usually given in meters—and the charging current of the antenna circuit—given in amperes. In deciding upon the value of meter amperes that would be required at our Long Island station, we took advantage of the experience gained from work done with the signals transmitted from the Nauen station in Germany and the Carnarvon station in England. As a result of the preliminary work in this connection, a figure of 50,000 meter amperes was decided upon and the antenna circuit was designed to give this value with full power on one transmitting unit.

As this figure of 50,000 meter amperes is made up of two factors, effective height of and current in the antenna circuit, the values assigned to each of these factors must be so chosen that the cost of the antenna, cost of power equipment, and cost of operation and maintenance will result in the most economical investment. In order to determine the most economical height of antenna, it was necessary to check carefully the varying effects of capacity, effective height, wave length, voltage and current. The result of these investigations showed that if the first cost of the transmitting station be plotted against the height of the towers for a given value of meter amperes at a given wavelength, a curve is obtained showing a distinct minimum. This minimum is not sharp but shows that there is a minimum cost of station for the given meter ampere value over a small range in the height of the towers.

Fig. 1 gives for comparison the principal dimensions, effective height, and resistance of the four types of antenna used in the Atlantic shore stations of the Radio Corporation. The effective heights are determined by measurements of radiation.

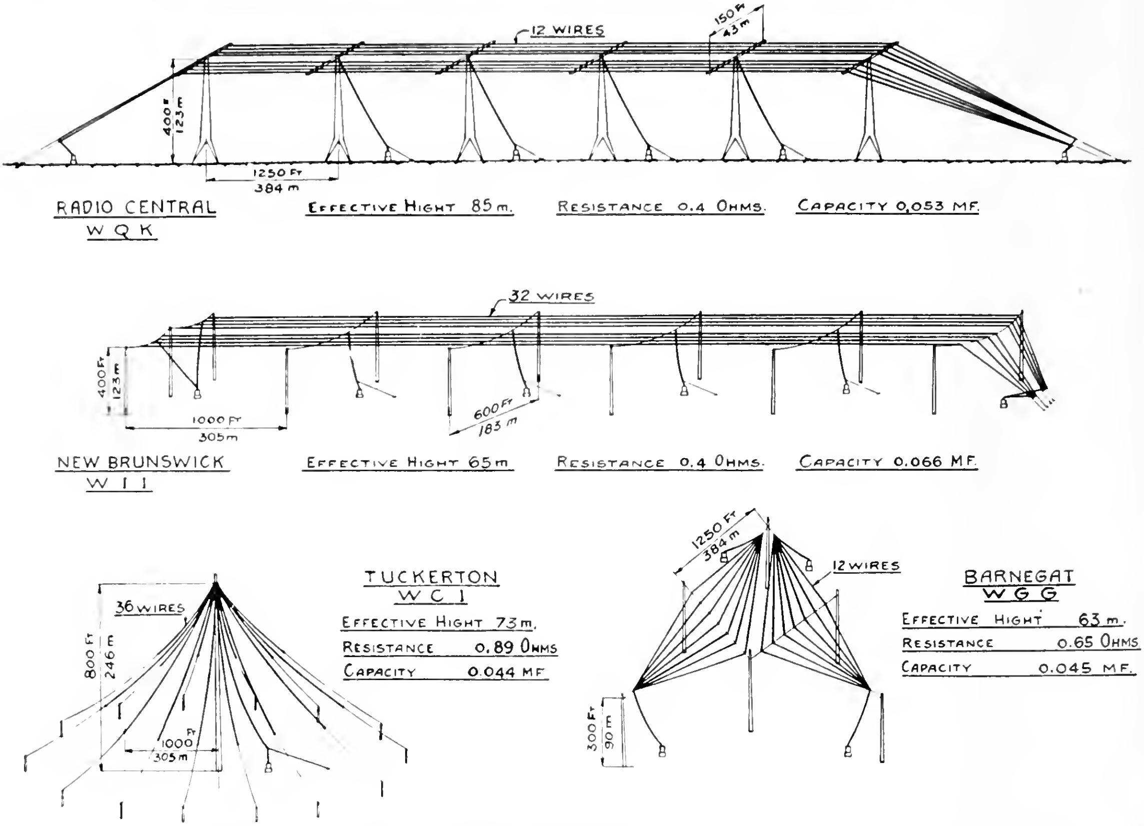

Fig. 1. Principal Dimensions and Other Data of the Types of Antenna Used in the Atlantic Shore Stations of the Radio Corporation

Fig. 2 shows the calculated cost for antenna structures at different heights for two typical stations of 50,000 and 100,000 meter amperes radiation.

The antenna voltage limitations which had been experienced at our older stations necessitated an investigation of the insulators that should be used in connection with these antennas. This work has been described in a paper read by Mr. W. W. Brown on March 7th last, before the Institute of Radio Engineers, and this shows that by careful design and arrangement of parts, we have been able to raise the working voltage of our antennas from around 60,000 to 150,000. In a recent test of the insulators actually installed and operating at our Radio Central station at a voltage of approximately 120,000, it was found that the voltage distribution over the double insulator unit, by means of which the wires are suspended from the bridge arm of the towers, is roughly 45 per cent and 55 per cent, the insulator nearer the tower having the smaller proportion of the voltage.

Power

The power to operate the station is generated in the Long Island Lighting Company's plant at Northport, L. I., and carried by a three-phase network at 22,000 volts, a distance of 30 miles to the radio station. At the radio station, the power is transformed to 2300, two-phase, to drive the induction type motors connected through step-up gears to the high-frequency alternators.

Antenna

The suspension of the antenna wires followed current transmission line practice. The wires run the full length of the antenna; standard transmission line clamps are fastened to the wire at each tower suspension point. These are shackled to the insulators suspended from the tower bridge arm. As the working voltage at which this antenna would operate, was higher than that used at our other transoceanic stations, the design of this circuit was carefully considered with respect to corona losses. The operation of this antenna at 135,000 volts showed that the corona limit was not reached on any portion of the circuit, although there is not a very great reserve where the inner wires, unshielded by the suspension insulators, pass across the face of the steel tower.

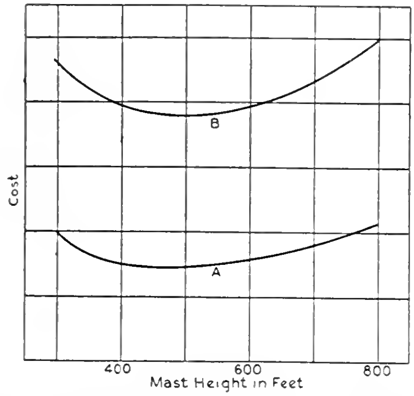

Fig. 2. Curves of Cost of Antenna Structures of Different Heights (*A* for 50,000 meter amperes radiation; *B* for 100,000)

The antenna consists of 12 parallel wires $\frac{5}{16}$ in. diameter 7500 feet long and spaced on an average about 14 feet apart forming an approximately horizontal plane about 150 feet wide. The wires are stretched from dead end structures close to the building to the first tower cross arm, then from cross arm to cross arm in a straight line to the sixth tower, then again to a dead end structure at the ground level at the far end.

The self-supporting type of tower was selected for use with this antenna. It is equipped with a bridge arm, its length 150 ft. over-all—fixed to the top of the tower. The insulators carrying the antenna wires are suspended from the lower face of this bridge. Many reasons entered into the decision to use this type of tower, three of which may be mentioned here. One consideration was the average height of the antenna wires. With a group of similar antenna wires, equally loaded, suspended on a springstay between two towers, the height above ground of the point of suspension of a wire decreases as the distance between this point and the nearest tower is increased. With a similar group of wires suspended from the bridge arm of a tower, there is no similar variation.

Another engineering consideration was the variation in antenna constants caused by high winds. The suspension of the group of antenna wires from a springstay slung between the tops of two masts or towers, has been used at our New Brunswick, Marion, and similar stations. It has been found that whenever there is a high wind blowing across the antenna wires, the springstay assumes a new position varying with the strength and direction of the wind. With gusty winds of high velocity, this change of position is continuously occurring. There is, in addition, the variation in the position of the antenna wires due to the cross wind on the wire span between the springstays. The result of these changes in position of the wires is that the constants of the antenna circuit change, and detune the antenna from the alternator which is operated at an accurately regulated wave-length. The resulting fluctuations in radiation have been so great at times as to seriously impair the commercial effectiveness of this station. Now, with a fixed point of suspension, such as the tower bridge arm, the only variations in position of the wires are those due to the wind on the wire span between the towers. Those due to the variation in the position of the springstay are not present.

The antenna circuits at all of our stations are equipped with variometers to correct for these changes and our experience is that the variations are less severe with Radio Central type of antenna than with that of New Brunswick.

As Long Island is well within that zone of the United States in which sleet and glare formation must be expected on all structures exposed to the weather during the winter months, provision has been made to melt such ice as may form around the antenna wires. The heating current for sleet melting is supplied from the power house, at 60 cycles, through special transformers and reactances. The antenna wires are connected together at the far end of the circuit. By opening switches at the power house end of this circuit, the wires can be disconnected from the radio frequency feeder circuit and the 60 cycle power circuit can be connected. If the several downleads were connected directly to the antenna wires throughout their length the path of the heating current would be short circuited. Two satisfactory methods have been used to avoid such short circuit. One method consists in dividing the wires into four groups and connecting only the wires belonging to one group at each of the four intermediate points. At both ends, all wires are connected. The other method consists of making the connection of each wire through a specially designed condenser.

The inductors used at each downlead of the multiple tuned antennas are installed without any protection from the weather. This type of installation has proved satisfactory except at some locations close to the sea where the spray from the sea water deposits salt on the insulators.

The standard outdoor coil is shown in Fig. 3. Fig. 4 shows coils housed in frame structures lined with copper.

At stations where more than one antenna circuit is installed, attention must be given to the disposition of the several antennas and of their individual feed circuits in order to minimize their mutual interaction. In enlarging or remodelling an existing station, it is not always expedient to attempt to bring all antenna circuits to the close proximity of the power house. This is particularly true of a station where the original antenna circuit is of umbrella design and where a second antenna circuit is to be installed, which can be operated simultaneously with the first and on a long wavelength differing from that of the first by only a few per cent. Such a situation confronted us at our Tuckerton station. The space immediately surrounding the power house was occupied by the umbrella antenna, which was in continuous commercial use. The new antenna could be erected on some vacant land just beyond the boundary of the space occupied by the umbrella antenna provided this antenna circuit could be fed with power at radio frequency from the power plant. The study of a transmission line that would be suitable for supplying to this antenna from the power plant, 200 kw., at frequencies of around 18,000 per sec. with little loss on the line, disclosed that this was quite practical. The antenna has been erected, this high-frequency line has been installed and the circuit has been operated very satisfactorily now for over a year. The power delivered to the antenna circuit is 92 per cent of the power supplied to the line.

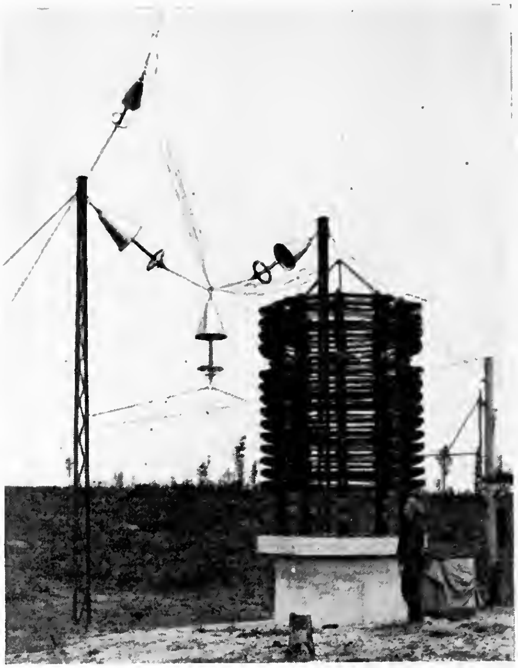

Fig. 3. Standard Outdoor Inductor Coil for Multiple Tuned Antennas

The success of this type of antenna feed circuit will have a profound effect upon the design of stations operating two or more antenna circuits simultaneously.

Grounding System

The first decision to be made in the development of the ground system was whether it should be of the buried wire type, or the type known as "counterpoise" or "earth's green." The New Brunswick station has a ground system combining counterpoise and buried wires. Experience had shown that while the counterpoise type might be ideal, from a theoretical point of view, it would be undesirable from the point of view of practical maintenance.

A counterpoise consists of a network of wires mounted on poles. These wires carry fairly high potential and the failure of any one wire will cause interruption of service until the fault is located and repaired. The overhead system of wires is also undesirable because it is an obstruction, making the maintenance of the overhead antenna wiring difficult and expensive. Theoretical considerations indicated that a buried wire system would be as effective as an insulated counterpoise provided that its dimensions and design were carefully planned with reference to the character of the soil.

Fig. 4. Coil Similar to That of Fig. 3, but Housed in a Frame Structure Lined with Copper

To determine the basic factors for the design of a buried ground system, measurements were made of wave propagation on wires of different lengths buried in the Long Island soil. As a result it was found that the velocity of wave propagation on a wire in this soil is about one-tenth of the velocity of wires suspended in the air. It was found, furthermore, that the resistance of the wire is a function of the wavelength. With increasing length of the wire, the conductivity increases as a linear function up to a length of one-quarter wavelength, where it reaches a maximum, after which it becomes a periodic function of the wavelength and the length of the wire. The results of these measurements showed that the maximum length of wire which could be used effectively must be something less than one-quarter wavelength of the wave propagation in the buried wire.

Measurements of wave propagation in the buried wires indicated that while lengths as great as 1200 feet could be used economically in the Long Island soil, it was furthermore determined, through calculations of the electric field distribution around the antenna, that 76 per cent of the electric lines of force radiating from the antenna would be collected by these ground wires if they were made 1000 feet long. One thousand feet on each side of the center line of the antenna was therefore considered sufficient; the result is that the Long Island antenna, in effect, stands on a plate of copper 2000 feet wide and 3 miles long, and therefore the functioning of this antenna is made independent of the resistance of the soil.

The combined antenna and ground system offers a total equivalent resistance to the antenna currents of only 40 hundredths of an ohm, made up as follows:

Radiation resistance at 16,500 meters	0.05 ohms
Ground resistance	0.10 ohms
Tuning coil resistance	0.15 ohms
Conductor resistance	0.05 ohms
Insulator and other losses	0.05 ohms
Total	0.40 ohms

The unit is operated with 200 kw. in the antenna, and the antenna current is 700 amperes, resulting in a radiation of 60,000 meter amperes.

A special plow was constructed by which the wires could be laid cheaply. The plow carried a coil of wire. It had a blade which introduced the wire in the ground at a depth of twenty inches. The plow was drawn by two Ford tractors.

The ground network consists of wires each 2000 feet long buried in the ground a depth of 15 to 20 inches in lines at right angles to the line of the antenna with the center point of the ground wire under the center line of the antenna. The ground wires are spaced 10 feet apart and as the antenna is 7500 feet long there are therefore 750 such wires making the total length of buried wire approximately

1,500,000 feet. The ground wires are connected to a heavy underground bus which runs in the ground under the center line of the antenna. There is also an aerial bus feeder which is connected to the buried bus through inductive reactances in such a manner as to make all paths to ground of equal reactance, resulting in equal distribution of the antenna current to all sections of the ground system.

Constancy of Wavelengths

A factor of great importance is that of maintaining the frequency or wavelength radiated absolutely constant for reasons that will be referred to later. In radio stations using high-frequency generators of the alternator type the speed of the alternator determines the frequency of the waves radiated. In many other forms of transmitters the frequency is affected by the antenna constants if not actually controlled by the antenna, with the result that as the antenna wires are blown about by wind, and ground and insulators are affected by dry, wet or frosty weather, changes in frequency will constantly occur. In the case of the alternator the problem resolves itself into maintaining the driving motor at constant speed regardless of voltage or frequency fluctuations in the power supply or the telegraph load fluctuations to which it is subjected by the alternator. This is accomplished by a system of relays operated in synchronism with the telegraph key by means of which the voltage applied to the motor terminals and the resistance in series with the wound rotor is varied so that the motor torque is always just equal to the load to which it is applied. Tendency to change speed on account of the telegraph load is thereby eliminated. Speed fluctuations due to changes in the power supply are not so easily disposed of however. A portion of the generator output is utilized to energize a tuned circuit of low resistance adjusted to have a natural period slightly different from the frequency at which the generator is maintained so that if the alternator frequency varies only a few hundreths of one per cent in one direction, there will be a large increase in the current in this resonant circuit, or if the variation is in the other direction, there will be a correspondingly large decrease. A portion of the current in this resonant circuit is rectified and we are thus provided with a direct current which varies up or down practically instantaneously with the slightest change in the alternator frequency. This direct current is made to control the voltage supplied to the motor terminals reducing the voltage to counterbalance a tendency towards increase in speed and vice versa. In order that there may be a visual indication of what is going on, a recording ammeter is inserted in the rectified current circuit; a fine straight line on the ammeter chart indicates a constant frequency, a thick line indicates small and continuous variations of frequency, and so forth. Under usual conditions of operation, irregularities of the ammeter chart line can be included within two parallel lines ⅛ in. apart representing maximum frequency variations not exceeding one in 5000 or 4 cycles per second, or 3 meters when operating at 20,000 cycles and 15,000 meters.

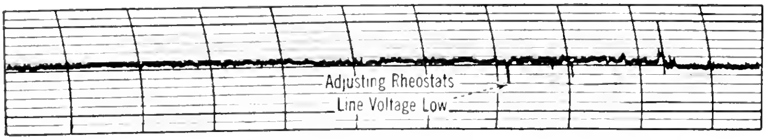

Fig. 5. Section of Speed Control Ammeter Chart of the New Brunswick Station

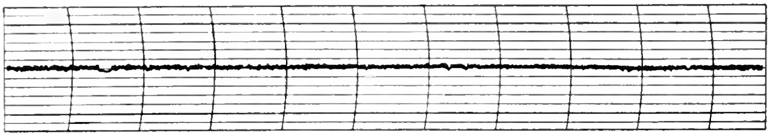

Fig. 6. Section of Speed Control Ammeter Chart of the Radio Central

Fig. 5 is a section of speed control ammeter chart from the New Brunswick station; the irregularities in this chart are due to various adjustments being made while in operation.

Fig. 6 is a section from a speed control ammeter chart for one of the transmitters at the Radio Central Station.

Fig. 7 is the corresponding section of the wattmeter chart of the same transmitter.

Receiving System

The centralized receiving system is located at Riverhead, Long Island. The antenna is of a new type which gives uni-directional reception. This system is so oriented as to receive signals from the over-ocean transmitter and annul signals from all other directions, including the powerful home transmitter nearby.

The antenna consists of two copper wires strung on ordinary poles like a telephone line, and extending over a distance of nine miles (15,000 meters). This antenna feeds a number of separate receiving circuits of different wavelengths without the slightest mutual interference or weakening of the signals.

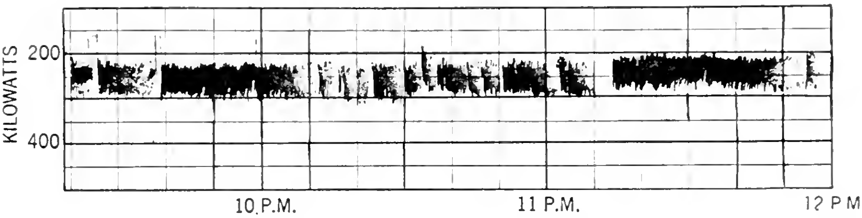

Fig. 7. Section of Wattmeter Chart of the Radio Central

Important as it is, from the point of view of centralization, to be able to receive an indefinite number of signals from the same antenna, the greatest importance in the use of this new receiving system is its remarkable properties of suppressing atmospheric disturbances or the so-called "static" which hitherto has been the bane of radio communication. The attainment of these results is not an accident; it is the result of development work covering a number of years. The "wave antenna" as now used in Riverhead is the practical answer to the receiving problem of today. The principle of directive reception has almost unlimited possibilities, and, by economic laws, the receiving system should be developed along these lines until its cost begins to equal the transmitting system. Then will the total cost of a complete circuit, transmitter and receiver reach its ultimate minimum. However, this economic balance is far from reached as yet. The principles of reception by long antennas were laid down in two papers presented to the A.I.E.E. in 1919, one by Weagant describing a system of balanced long loops, and the other by Alexanderson describing a system of open wires balanced against each other.

In this development the controlling idea is a mental picture which we now have of the nature of the disturbance which we wish to suppress. We call it "static" because it was assumed, in the past, that it was of the nature of static electricity. The hypothesis which is the basis of our modern work is, however, different. We imagine the ether as a disturbed ocean with waves of every length rolling in from all directions. These waves are of the same nature as the signal waves. Those disturbing waves which are of different wavelength from our signals can be shut out by the same means as we use for shutting out other signals, that is, by tuning. But the disturbing waves which have the same wavelength as our signal and are in all respects of the same nature, pass through our tuning system like the signal. We must therefore find some basis for discrimination other than wavelength.

If we can construct a receiver which is sensitive only to waves coming from one direction, then we can shut out waves from all other directions, even if they have the same wavelength. This idea started us on the work of directive reception. Theoretically, there is no limit to the improvement attainable in this direction. We might build a receiving antenna focussed on one transmitting station in Europe, but such receiving antenna would cover a very large area.

A complete theoretical analysis of the wave antenna has been given in a recent paper this year before the A I.E.E. by Messrs. Beverage, Rice and Kellogg. For those who wish only to understand the characteristics of our modern receiving system, in order to make use of it, the following popular explanation may be of some guidance.

Imagine the antenna to be a long, narrow lake, and that the wind is the incoming signal, and further that a cork floating on the waves of water that beat against the shore is the detector. If the observer stands at one end of the lake, he will observe waves beating against his shore only when the wind blows lengthwise to the lake and from the end opposite to this location. When, on the other hand, the wind blows from his end of the lake, the beating waves appear at the opposite end, while his shore is calm. This, at least, would be the case if the lake has smooth sand beaches on which the waves could spend their energy without reflection. But, if the lake ends have steep rocky shores, the water waves will be reflected back and forth and thereby make the surface of the whole lake rough. The waves, which indicate the "signal wind," would thus appear at both ends of the lake, regardless of the longitudinal direction of the wind. This reflection must be avoided. The wave antenna is therefore made with ends corresponding to the sandy beach. The antenna terminates in a resistance which is carefully adjusted to absorb all save energy and reflect none. The practical advantages of the use of the wave antenna are the elimination of about 90 per cent of the extraneous disturbances known as static.

A valuable practical feature of the form in which the wave antenna has been developed is the method of reflecting the signal so that the "surge resistance" which absorbs the static can be located in the receiving building. This is accomplished by erecting a two-wire line and making the same two wires function both as an antenna and as a transmission line for radio frequency waves. The two wires in parallel act as the antenna. At the far end of the line they are connected together through the primary winding of a special transformer. One end of the secondary of this transformer is connected to the middle point of the primary winding; the other end is connected to ground. The secondary winding feeds the current back into the two wires in series as a transmission line and a second transformer at the front end of the line couples the transmission line to the receiving set. The midpoint of the transformer winding connected to the lines is grounded through the "surge resistance." By this connection, the windings on the two halves of the transformer are opposed for currents flowing over the two wires in parallel; that is, for the antenna effect, and produce no effect upon the receiver.

The resultant reception characteristic curve shows that reception residuals of static of a few per cent may occur in certain directions in the back area of the diagram. The residuals are practically negligible in most cases, but when there is very strong interference or strong sharply directional static in their general direction, an appreciable improvement may be obtained by balancing the residuals to absolute zero for some particular direction in the back area. This is illustrated by Fig. 8.

The final balancing of static and interference is accomplished by the use of an artificial line. This line is fed by currents coming from only the same direction as the undesirable residuals. The phase of these currents may be made anything desired with respect to the phase of the residuals in the secondary of the transformer to which the surge resistance is connected. By making the intensity of the voltage on the artificial line the same as the residual voltage intensity, and by making the phase displacement 180 degrees, the residual currents are readily balanced for any particular direction in the back area.

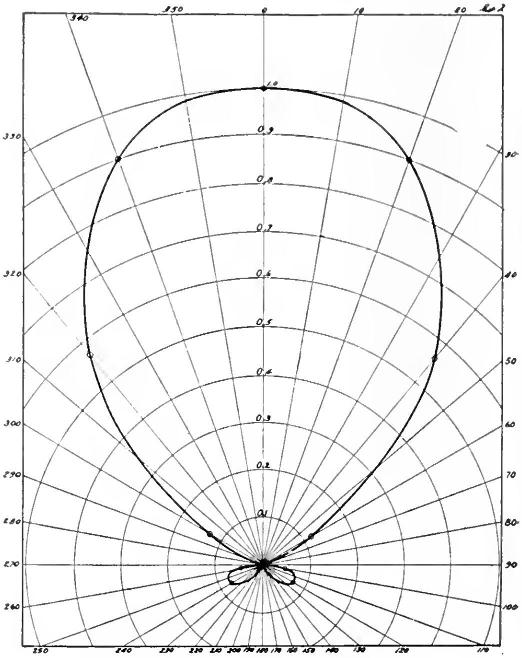

Fig. 8. Directive Curve of Wave Antenna

With this antenna system, extremely satisfactory multiplex reception is being carried out at Riverhead. Six sets of receiving equipment are normally coupled to this one antenna system, and the signals on six transoceanic circuits are separated by tuning, and copied simultaneously, each independent of the electrical operation of the other sets.

For the purpose, the antenna output transformer is built with several secondaries and the artificial lines are made up to accommodate a number of receiver sets. Many precautions are necessary in the design and arrangement of the receiving equipment to eliminate cross talk and "beat note" interference between the different sets. With this end in view, an equipment for reception of long waves has been completely remodelled.

In the first place, all of the different elements in each receiving set must be thoroughly shielded. The tuning inductances are all balanced pairs of coils placed in an inner shielding of copper to eliminate the losses in the iron casing of the outer shield. In spite of the shielding, cross talk and beat note interference occurred until suitable chokes and filters were placed in both the positive filament and positive plate leads of all coupling tubes, amplifiers, detectors, and oscillators.

Fig. 9. General View of the Receiving Equipment at the Riverhead Station

The receiving apparatus is arranged in line with the antenna input panel at one end and the audio-frequency output panel at the other end. The intervening units are placed in correct sequence so that the signal currents pass in progressive order along the line through all the various units from input to output panel without looping back over this same path.

The elements of a set are mounted on a sub-panel which is placed in an iron box, the front door of which may be opened. All adjustments of tuning and filament control which are likely to be made frequently on a set tuned to a fixed wavelength can readily be made without opening the front door of the iron boxes because such control handles are mounted on the outer doors in such a manner as to engage with the controls on the sub-panel when the iron door is closed.

These receivers are set up on racks holding three sets per rack. Each set is arranged as a complete unit on a shelf and the shelves are arranged in three tiers on the racks. The Riverhead station is equipped with three racks making space for the accommodation of nine receiving sets.

Fig. 9 gives the general view of the receiving equipment.

The signals received from the wave antenna are strong; so usually a total of four stages of amplification is sufficient to bring the intensity of normal European signals up to a strength that is rather uncomfortable to the ear.

Since all the local long wave stations, except Marion, are either behind or in the case of Rocky Point, at right angles, to the direction from which the European signals come, directive reception alone lowers the intensity of the local stations so much that tuning can easily eliminate their interference. Interference as strong, for instance, as that from Marion, can be eliminated when the wavelength differs by not less than 3 per cent. For interference of considerably less intensity than that from Marion, as for instance, that from stations in Europe, or from a local station, reduced by directive reception, a 2 per cent difference in wavelength is sufficient.

For wavelength difference of 2 per cent and less the constancy of frequency of the transmitting station becomes of very great importance. Extremely good frequency regulation at the transmitting station will allow the use of filter circuits by means of which interference on wavelengths differing less than 2 per cent from that of the desired signal can be eliminated.

The receiving station at Riverhead, L. I., is about 70 miles east of New York and the next phase of the problem was the automatic transfer of the radio signals to the central control office in New York City in order to eliminate the double handling of traffic, the slowing up of the circuit, and the other delays inseparable from the older system. The requirements of this circuit were studied and then the American Tel. & Tel. Co. was requested to provide a suitable tone circuit from Riverhead to our Broad Street office, New York City. For a period of several months experiments were conducted over this temporary line, during which it was demonstrated that it was feasible to send these tone signals over a 70-mile circuit without detriment to the readability of the signals. Continuous commercial operation over a single tone circuit was started about July 1, 1921. Subsequently additional tone circuits were built for the commercial operation and control of Riverhead station in this manner.

Central Operating Room

The operating room at the city offices is the place where the written message is converted to the dot and dash of the Morse code. The continental code is used in radio as in all other international telegraphic communication. During the last few years a great change has taken place in the transmission of the message. Whereas formerly the manually operated telegraph key was used almost universally for speeds of transmission of 40 words per minute or less, this has been entirely displaced by the machine transmitter. The advantages of machine transmission over hand transmission are (1) that the operator is required to work a typewriter keyboard only and need not necessarily be a skilled telegraphist; (2) that one operator can transmit messages in this manner at rates up to 100 words per minute, whereas the best that can be done by hand is 35 or 40 words per minute; (3) that all characters are perfectly formed and do not vary with the different operators, and (4) the machine is tireless and has no lost time. The telegraphic manipulation is actually accomplished by first punching the message on a paper tape and subsequently passing the punched paper tape through the mechanical transmitter which is an automatically operated telegraph key.

The transmitter sends telegraph impulses over the control wires between the city office and the transmitting station and operates the relay system at that station.

In order that a check can be kept on the performance of the automatic transmitter, the control wires, and the relay system of the transmitting station, a radio receiving set is provided at the city office which makes audible or visible to the operator the actual signal being transmitted into the ether. This receiver is a very simple piece of apparatus, since the reception of the signal from the nearby hand power transmitter is not at all difficult, although of course, as there are so many transmitters operating in one locality with only small wavelength separation, very efficient tuning equipment must be provided.

The reception of a message at the city office requires a reversal of the above process. The signal as received at the receiving station is in the form of audio frequency current, the frequency of which is variable as desired, these signal currents are transferred to the city office by telephone wires. At the city office it is necessary to further amplify the currents before they are introduced into the telephone or the recorder. It is possible to use aural reception at speeds up to 35 or 40 words per minute. Better speeds can be secured at times by a combination of aural and recorder reception. At speeds over 40 words per minute tape reception must be used exclusively. It is possible for some tape readers to copy as fast as 60 words per minute but generally for speeds over 40 words per minute, the work is divided up among an increased number of operators; 40 to 70 words per minute two operators; 70 to 100 words per minute three operators, and so forth. The development of the tape recorder used for transoceanic radio reception was ably described in a paper presented to the Inst. of Radio Engineers by J. Weinberger in 1921.

The electrical equipment of the operating room of a city office, handling a large number of circuits, requires careful planning. In the city office of the Radio Corporation of America at 64 Broad Street, New York City, there are at present in continuous operation,

6 transoceanic receivers
6 load Monitor receivers
6 automatic transmitters

and over 30 land wires. To these will soon be added a number of new services.

Power supplies of different types are provided for the various electrical and mechanical devices and measures have been taken to prevent inductive interference effects between instruments.

Wavelength Distribution

The economical wavelength for communication over a certain distance can be selected by the practical rule that the economic range of a station for reliable communication is about 500 to 1000 times the wavelength. If too short a wave is selected the signals will be weak in daytime and strong but variable at night. This variation is most noticeable during the period when darkness exists over the area between the communicating stations. In some parts of the world it is possible to use short waves to advantage because the absorption is comparatively lower than on long waves and variations are unimportant but generally speaking for distances over 3000 miles the reliability of wavelengths of over 11,000 meters is so much greater than that of shorter waves. Long waves have therefore been universally adopted. for long distance communication.

It can now be readily seen that since the ability to receive distinct signals depends on the separation of different frequencies there is a definite limit to the number of "channels" of communication between stations that can be set up.

If the wavelengths between 11,000 and 22,000 meters are divided into 2 per cent bands there are 35 "channels." If into 1 per cent bands, there are 70 "channels." Except to such extent as directional reception will permit the number of one way channels open for such long distance communication is limited to the number of these bands.

If we suppose our plans to be based on the use of 1 per cent bands, it is evidently necessary first that each transmitter shall cause no radiation outside of the 1 per cent band allotted to it and furthermore shall maintain its actual radiation frequency exactly on the center of such band; and second that each receiver shall be capable of separation of currents from those differing only 1 per cent in frequency. The above requirements imposed upon the transmitter have already been proved practicable. But the realization of the full possibilities of radio communication requires that all transmitters of antiquated type which take undue space in the ether be replaced.

There are, however, other difficulties that cannot be so easily overcome. For instance, while it is quite possible for the receiving station to separate currents of frequencies differing 1 per cent if the voltages induced at the station at the different frequencies are equal, it is not an easy matter to separate the currents when the voltage induced in one case is 1000 times the voltage induced in the other. This is the situation where in the case of a transatlantic circuit the receiving station in America receives from Europe on 15,000 meters and the transmitting station in America sends to Europe at the same time on 15,150 meters. In such cases, as described above, it is necessary to increase the separation between frequencies to 3 per cent and in order that such large separation may not be too numerous a rule has been established by precedence and informal agreement, that all the transmitters in one locality shall transmit on wavelengths close together. We have such a case in the concentration of American transmitters between 16,000 and 17,500 meters. In this band of wavelengths there are operating at present the following stations:

15,900 meters Tuckerton No. 1 Transmitter
16,300 meters Kahuku No. 1 Transmitter
16,465 meters Radio Central No. 1 Transmitter
16,700 meters Tuckerton No 2 Transmitter
16,975 meters Kahuku No. 2 Transmitter
16,975 meters Annapolis Compensating Wave Arc
17,145 meters Annapolis Signalling Wave Arc
17,500 meters Radio Central No. 2 Transmitter

It is planned to operate transmitters in Sweden, Poland and Argentina in the near future on wavelengths 18,000 meters to 19,000.

The French Government station at Lyons operates at 15,500 meters and there are a number of additional European and American transmitters operating between that wavelength and 11,000 meters, while other Government and Commercial stations in France are at present operating at wavelengths from 19,000 to 22,000 meters.

The congestion of the ether is therefore not a mere matter of looking into the future, but a real present-day problem. The necessity for traffic regulation at least suffices to prevent reckless driving so to speak, is just as apparent as the undesirability of hidebound regulations until such time as the limit of possible improvements in technique have been more definitely determined.

Such is the present situation in the long distance radio ether. The congestion is due to the necessity for the use of the longer waves for long distance work and the fact that all high-power stations are broadcast stations; much improvement is possible in existing practice but radically new methods of operation must also be considered, such for example as directional radiation on shorter waves. With the realization of such possibilities the situation will take on a new aspect.

Project of New Communications

Sufficient statistics are now available by means of which the technical and financial possibilities of new circuits of communication can be accurately predetermined.

Fig. 10 shows the daily, monthly and yearly reception curves for a typical transatlantic circuit. The ordinates of these curves show the capacity of the circuit at the different times of the day and year respectively. By the capacity of the circuit we mean the practically possible speed of reception in five-letter code words per minute. The capacity of the circuit is a function of the strength of the signal and the intensity of the disturbance. The intensity of the signal is measured in absolute units of microvolts per meter. Fig. 11 shows a typical daily curve of variation of signal strength.

Experience has shown that under any given condition of atmospheric disturbance, there is a direct proportionality between the strength of the signal measured in microvolts per meter and the traffic capacity of the circuit measured in words per minute. The proportionality defined above is almost exact between the limits of oral reception ranging from 5 to 40 words per minute and it can be considered as substantially correct up to the highest speeds that are used. This simple relation between strength of signal and words per minute has given us a practical method of measuring the intensity of atmospheric disturbances.

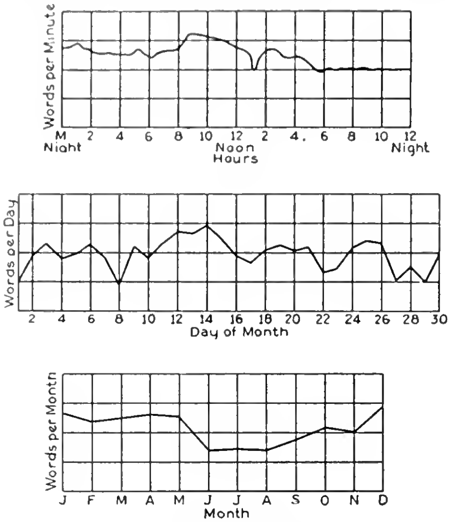

Fig. 10. Daily, Monthly, and Yearly Reception Curves for a Typical Transatlantic Circuit

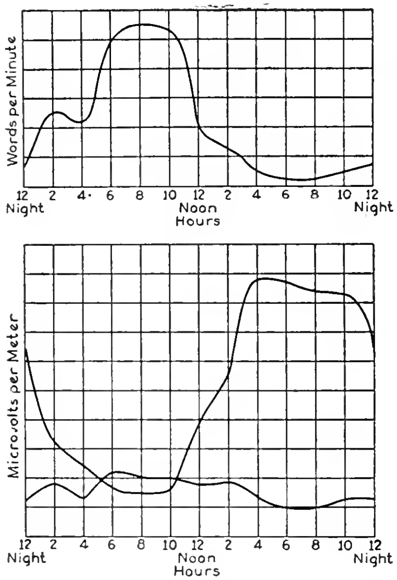

Fig. 11. Typical Daily Variation of Signal Strength and Disturbances Measured on a Simple Vertical Antenna

As an actual standard method of measurement an artificial signal is introduced into the receiving system and regulated so that the capacity of the receiver is 20 words per minute. The number of microvolts per meter which must be introduced to permit reception at 20 words per minute is thus a direct measure of the intensity of disturbance.

If a transmitting station is to be designed for a new geographic location, measurements of disturbances are taken in that location. The results of these measurements, which may be taken over a large part of a year, show what strength of signal will be needed during the different months of the year to carry a desired traffic. Fig. 12 shows a typical chart of this kind. Comparison between this chart and the known typical yearly chart for a transatlantic circuit gives a direct indication of the capacity of the new circuit in terms of the circuit in operation. The chart for the projected circuit shows the capacity of a 50,000-meter ampere and of a 100,000-meter ampere transmitting station.

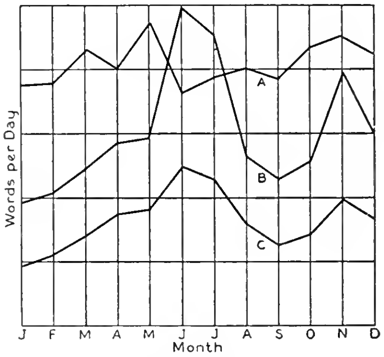

Fig. 12. Typical Yearly Readability Chart
A: East-West Circuit
B: North-South Circuit; 100,000 m.a.
C: North-South Circuit; 50,000 m.a.

Thus it can be stated that guess work has been eliminated from the developments of radio communication, and that sound foundations, both technically and financially, can be laid for all future expansions of our system.

Testing Transformers for Central Stations

By A. B. Hendricks, Jr.

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Tests of the dielectric strength of electrical equipment are as essential in its maintenance as in its manufacture. Such tests to be reliable, however, should be made with apparatus designed for the purpose. Too much is at stake to warrant an operating company placing reliance on makeshift paraphernalia, even though there may not daily be occasion to make such tests. For those who are concerned with the subject, the following article will be of great assistance. It calls attention to the necessary qualifications for reliable insulation testing and describes the various equipments standardized for this purpose and for high-current testing.—Editor.

The routine and special tests of apparatus and cables commonly carried out at central stations require testing transformers and auxiliary devices of a wide range of capacities and characteristics. Standardization of testing apparatus is desirable, alike from the standpoint of the maker and user, but so far has appeared almost impossible. The legitimate requirements show large variations, but the great number of special sizes and styles that have been furnished central stations reflect the ill-considered fancies and lack of foresight of engineers and operators and result in an excessive amount of special designing with consequent slow delivery and high cost. It is intended here to discuss the desirable characteristics of such apparatus and to describe representative testing sets, with a plea for the elimination of freak designs as well as those differing slightly from standard. The statements are necessarily of a general character because of the special nature of the problem.

General

The service requirements and characteristics of testing transformers differ widely from those of the usual types designed for power and lighting and are met by a distinct form, although there are similarities in fundamental structure. Many of the salient features of large power transformers were first developed and used in testing transformers. The special features are:

(a) High voltage.
(b) Low kilowatt capacity.
(c) Low reactance.
(d) Short time rating.
(e) Small size and weight.
(f) Means for varying and measuring voltage over a wide range.
(g) Ability to withstand short circuits and high-frequency oscillations.

The general form and many of the parts have been standardized and some parts such as terminals are made in quantities and carried in stock.

The standard frequency is 60 cycles, but 50 cycles is used for most sets for foreign countries. Many designs are made so they may be used at either frequency.

Standard ratings run from 3 kv-a. at 30,000 volts to 500 kv-a. at 500,000 volts with a large variety of intermediate ratings and special designs.

The high-voltage current is usually 0.1 to 0.5 or 1.0 amp. except for alternating-current cable testing where it may be of the order of 35 amp. at 30,000 or 60,000 volts representing 1000 to 2000 kv-a.

The reactance is about five per cent. This is the result of a large core and few turns in the winding, giving a substantial construction, voltage stability on the usual leading current, great accuracy of the voltmeter coil, and high power in the test circuit. It tends to small size but great weight, and for portable outfits a smaller core and higher reactance are sometimes necessary.

High-voltage tests seldom last longer than 1 to 30 minutes. The time ratings are usually from 1 to 4 hours for a 50-deg. C. temperature rise, but may vary from less than 1 second to continuous operation. At the higher voltages the limit is set by dielectric losses and danger of insulation failure rather than by the actual temperature of the winding.

Voltage variation may be obtained by field control and series-parallel connections of the generator (which is considered the best method) or by induction regulator, tap transformer, or series-parallel connections of the high-voltage transformer.

Sometimes a larger power generator is available, with field control. In this case some means of limiting the power and quickly opening the circuit is necessary, or a breakdown of the material or apparatus under test may be disastrous.

A separate generator of about the same rating as the transformer makes an ideal arrangement, but it is also the most expensive.

Perfect wave form under all conditions of load, power-factor, and excitation is the indispensable characteristic and is best attained by a generator with a revolving field of cylindrical form having a distributed winding in slots, resembling a continuous-current armature. A number of short-circuited field coils or, better still, a complete short-circuited squirrel cage in the same slots compensates for armature reaction and prevents wave distortion. Such a machine eliminates many corrections and uncertainties in testing and is well worth its higher cost.

The driving motor may be of a capacity one-half to one-third that of the generator as the power-factor of the load is always low. Direct connected induction, synchronous, or direct-current motors are all satisfactory but the last gives exact speeds, variable over a considerable range which is sometimes desirable.

High speeds (1200 to 1800 r.p.m.) tend to small size, low cost, close regulation, and good wave form.

High excitation, that is, at or above normal, gives stability of voltage and wave form and high power in the discharge circuit.

Unsatisfactory results follow an attempt to use a generator at normal current and low excitation. Distortion of wave form is accompanied by low power in the high-voltage circuit, and when arcing over or puncturing insulation a destructive high-frequency oscillation is set up, which may not be followed by a dynamic arc because of a sudden drop in voltage. If the voltage can be maintained sufficiently to form a dynamic arc, the oscillations are largely suppressed, as the arc short circuits the transformer. This applies more particularly to the testing sets of high power and voltage when used in tests such as those on line insulators, high-voltage terminals, and switches.

Transient oscillations lead to erratic results in testing, and are a disturbing factor to be avoided as far as possible.

It should be obvious that the best results are to be attained with any apparatus when operated at or near its normal rating, but many engineers do not seem to realize this. It is recommended that transformers be not used at less than one-fifth of normal voltage. This is an arbitrary figure, representing nothing but a compromise. At lower ratios the voltage becomes unstable, 5 per cent normal reactance representing 25 per cent at one-fifth voltage and this is particularly undesirable with leading loads.

Series-parallel transformer windings are often used on both sides of testing transformers, but complicate the construction and increase the size and cost. Double primaries and secondaries are practicable but to be avoided at voltages over 150,000.

Four primary (low-voltage) windings are sometimes used to give four voltage ratios; 100, 50, 33⅓, and 25 per cent of maximum rating. It is better to use four circuits on the generator giving the ratios 100, 75, 50, and 25 per cent as the 75 per cent ratio is more useful than the 33⅓ per cent.

Induction regulators are employed for voltage variation more often than other devices and are generally made for the full range from zero to maximum. This means that the transformer must be wound for double the line voltage, since the regulator doubles the voltage; a point often overlooked.

The fear is sometimes expressed that with leading loads the series impedance of the regulator may give resonance difficulties, either with the fundamental frequency or the harmonics. The value of the impedance is too low for such effects, and no trouble from this source has been reported.

Sometimes the voltage is controlled by generator field and induction regulator, but this represents an unnecessary duplication of function. Series-parallel armature windings of the generator insure operation at or near normal excitation and render additional devices unnecessary. The regulator impedance and exciting current would be likely to affect the wave form more than a small variation of generator excitation.

For cable testing there is some excuse for series-parallel high-voltage windings on the transformer, as these may be required to give large current at fractional voltage. In this case all the high-voltage leads are brought out to terminals on the cover and internal connection boards are never used. This is really a simpler, more compact construction, and more convenient in use.

Generator Testing

Ordinary testing transformers of medium capacity and about 30,000 volts suffice for high-potential tests of generator armatures and fields, except in large sizes. The kilovolt-ampere capacity required in the transformer varies so widely with the rating of the generator that no rule for determining it has been made. Medium and large size alternators for either steam or water turbines require from 25 to 100 kv-a. or more at 60 cycles and voltages up to 30,000.

Low-speed water turbine alternators take the largest charging current of any. Table I gives results of actual tests on representative armatures.

For ordinary generator armatures up to 1000 kv-a., the charging current is of the order of $\frac{1}{4}$ to $\frac{1}{2}$ amp. These figures apply to tests from one phase to the other two and core.

Cable Testing

High-voltage cables many miles in length take a charging current, and require a kilovolt-ampere capacity in the testing transformer much greater than might be supposed (sometimes running into the thousands at double voltage and normal frequency).

TABLE I

Kv-a.	Speed	VOLTAGE		Frequency	Trans. Kv-a.
		Rated	Test		
7000	90	13200	27400	36	422
33333	1800	14000	29000	60	100
700	900	13200	27400	60	50
1400	720	6600	14200	60	34
187	138.5	4000	9000	60	25

While the formulas for calculating cable constants are well known, they are given in a variety of inconvenient and confusing forms in the reference books and are therefore inserted here in the form which has been found most useful.

The electrostatic capacitance of a single-core cable is:

$$C = \frac{K}{59 \log_e \frac{R}{r}} \text{ microfarads per 1000 ft.}$$

K = Specific capacity of insulation
= (approx.) 3 for paper, 4 for varnished cloth, 5 for rubber
R = Inner radius of sheath
r = Radius of conductor

The charging current is:

$I = 0.377\ CE$ at 60 cycles
I = Amperes (effective)
C = Microfarads
E = Kilovolts (effective)

The maximum voltage gradient is:

$$G = \frac{E}{r \log_e \frac{R}{r}}$$

E = Applied voltage
G = Voltage gradient in same units as E, R, and r.

There is no simple expression for capacitance, or maximum stress in a three-core cable.

The charging currents for three-core cables vary with the nature of the connections, approximately as follows:

Test between 3 cores and sheath = 100 per cent current

Test between 1 core and (2 cores and sheath) = 55 per cent current

Test 3-phase (per core) = 38 per cent.

The charging current is proportional to frequency and voltage and this has led to the suggestion to reduce the cost of the testing apparatus by reducing the frequency. This is fallacious because the cost per kilovolt-ampere increases as the frequency decreases. In general, nothing is to be gained by reducing the frequency below 50 or 60 cycles, and these values are recommended.

Cable testing sets are usually built single-phase although three-phase sets are occasionally used for the sake of speed in testing three-core feeder cables.

Since the load is practically at zero power-factor 90-deg. leading current, the terminal voltage will be increased by the reactance of the transformer and regulator or generator. This may be compensated in the rating of the generator, transformer, and single-phase regulator, but not in a 100 per cent raise and lower three-phase regulator. The reason is that voltage variation is by simple addition and subtraction in a single-phase regulator, but by phase rotation in a three-phase regulator.

In the latter case, if the primary and secondary voltages are made unequal the test voltage cannot be reduced to zero by the regulator alone.

Balancing the charging current by parallel inductance

The leading charging current of the cable may be balanced by the lagging exciting current of an inductance connected in parallel with the cable thus reducing the kilovolt-ampere capacity required in the generator, regulator and transformer. The two currents being nearly in opposition, the resultant is small and in practice the kilovolt-ampere capacity of the supply circuit and apparatus is reduced to 20 per cent or less of the kilovolt-amperes represented by the cable charging current.

An inductance for cable testing resembles an ordinary testing transformer but has a series of small air gaps in the middle leg of the core, a high-voltage winding with taps, and no low-voltage winding. The standard ratios of kilovolt-ampere capacities are:

Inductance; 100 per cent cable load, with taps down to 40 per cent.
Transformer; 20 per cent load.
Regulator; 10 per cent load.
Generator; 20 per cent load.

This combination gives 0 to 100 per cent capacity, literally it gives 120 per cent, but the inductance is always made 100 per cent and the 20 per cent transformer capacity, which really adds to it, covers any lack of balance which may exist.

Air-gaps in Transformer Core

Transformers are often made with air-gaps in the core, proportioned for 50 per cent exciting current; the high-voltage winding being of 100 per cent capacity, the low-voltage of 50 per cent, regulator 25 per cent, and generator 50 per cent.

The currents in the low- and high-voltage windings, throughout the range of operation, are then approximately as follows:

HIGH VOLTAGE		LOW VOLTAGE	
Amp. Per Cent	Phase	Amp. Per Cent	Phase
0		50	Lag
50	Lead	0	
100	Lead	50	Lead

Such a transformer will carry full-load current on the high-voltage side, only when it is leading. It will carry no lagging high-voltage current without overloading the low-voltage circuit.

The input to the transformer with 50 per cent exciting current is 50 per cent of the load, with the balancing inductance it may be 20 per cent or even less.

Danger of resonance has been suggested in connection with the inductance, forgetting it is intended for current resonance and being in parallel with the cable can do no harm.

Cable Testing by direct current

A high-voltage three-phase cable 10 miles in length may require a capacity in the testing apparatus of the order of 10,000 to 15,000 kv-a. at 60 cycles.

Reduction of frequency is of no assistance in this problem, but with a direct-current testing set the case takes a new aspect. It has been found possible to maintain 15 miles of 33,000-volt cable at 100,000 volts, direct-current, with a steady input of 50 watts.

The hot-cathode rectifier or kenotron has been applied for this purpose and a number of these outfits are now being used by central stations.

Direct-current testing sets for 100 and 200 kv. are practically standardized. These are composed of the following main parts:

A high-voltage testing transformer is used with induction regulator for voltage control. Transformers vary in capacity from 5 to 50 kv-a. and 44,000 to 88,000 volts. A 60-cycle 220-volt source is the most suitable for all excepting the largest sizes when 440 or 2300 volts may be used. Supply voltages above 440 increase the cost and decrease the safety in handling.

The kenotrons used are standard 250-milliampere tubes with a 50,000-volt direct-current rating. For sets of 50,000 volts or less a single tube is used. For higher voltage sets, two or more tubes in series are used so as to limit the voltage across each tube to a safe value. The filaments of the tubes are supplied from individual filament transformers insulated for the maximum voltage at which the tube operates. Rectification of one-half of the wave is generally used but the sets are often supplied with a second set of kenotrons to rectify the other half of the wave for testing three-core cables.

A power limiting reactance for protecting the kenotrons in case of cable failure and during fault reduction is usually placed in the low-voltage supply circuit.

A small capacity (2.5 to 10 kv-a.) transformer of moderate voltage (2.5 to 10 kv.) is frequently used for completing the burning down of failures to a low-resistance ground.

With larger sets a switchboard is used, mounting crest voltmeters for indicating the direct-current test voltages and ammeters for reading the values of direct current in the various circuits.

The question which first arises is: *What is the ratio of direct to alternating voltage for the same test results?* There is not, and in the nature of the case there cannot be, a definite answer to this question. The first assumption would be that the direct voltage should be the same as the crest value of the alternating voltage for the test desired, but in practice the ratio has been found much greater than this, except n some ideal cases where the maximum value alone was the determining factor such as in using a sphere-gap.

Present practice favors a direct voltage of over two times (in some cases 2.4 times) the effective alternating test voltage in cable tests. Conditions vary so much that no definite rule can be given for general application, but the type of cable insulation and other factors (such as the temperature of the cable at the time of test) must be taken into account. It has been found that the direct voltage must be higher than was originally expected.

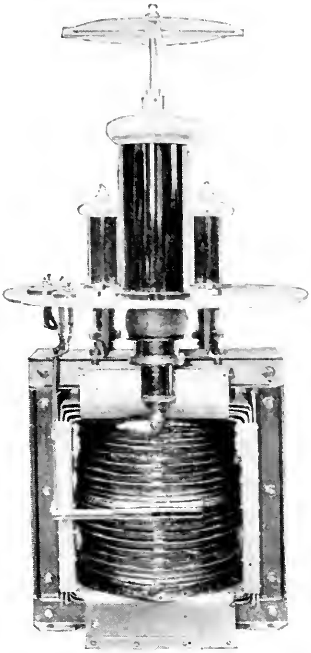

Fig. 1. 200-kv-a., 75,000/150,000-volt Transformer

Roughly, in short-time tests the dielectric strength of solid insulating materials varies more or less as the square root of the thickness for alternating voltage and more or less directly as the thickness for direct voltage, which means that the direct-current testing set must give very high voltage when used for breakdown on the best type of cable for 33,000 volts or more working pressure.

The direct-current set is lighter, less expensive, and requires less power for operation than the alternating-current set, but is more complicated and delicate in construction and operation, requires about the same space and does not give exactly the same test as alternating current. For long high-capacity cable, it is the only available and practical means for making tests.

In operation the voltage is brought up gradually so as to prevent a rush of current. When the cable is fully charged the load will be small since the current is limited to the leakage loss current.

Transformer Design

A high-voltage testing transformer of typical design is shown in Fig. 1 as it appears when taken from its tank. This is one of a set of three built for three-phase tests in a cable factory, but gives a good idea of the construction of the whole series of sizes and styles.

Core and Tank

The core is of the vertical three-legged type, all windings being on the middle leg, which is cruciform in cross-section and composed of three widths of plates. The core clamps are steel channels held by through-bolts insulated with fiber tubes and washers. The core is suspended from the steel plate cover by hangers made from steel channels or I beams. The hangers are made as short as possible, the length being determined by the distance needed for the terminals.

The tank is round, made of steel plate, with electrically welded side seams and flanged steel plate base, riveted and welded. A steel angle band is riveted around the rim of the tank, the rivet heads being welded on the inside and serves for bolting on the cover. A large number of hardened head cap screws and nuts are used for the bolts. The rim of the tank projects slightly above the angle band and is machined for a soft gasket, together with the under side of the cover at this point, to make an oil-tight joint. A single large eye-bolt is placed at the center of the cover for handling by a crane.

Winding and Insulation

The primary or low-voltage winding forms a thin cylinder surrounding the middle leg of the core and insulated therefrom by a cylinder of shellac-paper. The secondary or high-voltage winding consists of a series of disk coils of several turns per layer, wound on foundation rings of shellac-paper and insulated by one or more wraps of black varnished cloth tape. Paper ribbon is used for layer insulation. All the coils are dried in vacuum, impregnated with varnish, and baked before applying the outside tape. The major insulation between primary and secondary is formed of a series of concentric cylinders of shellac-paper interleaved with cylinders of black varnished cloth. The cloth projects at the ends where it is split and turned over to form flanges, interleaved with the moulded pressboard shields composing the main insulation between high-voltage winding and core.

This particular transformer is wound in two 75,000-volt sections and one terminal of one section is brought out to a film cutout on the cover, for connection through an ammeter to ground, while there are one 150,000-volt and two 75,000-volt terminals.

A voltmeter coil reading direct in kilovolts is placed between, but thoroughly insulated from, the two high-voltage sections and connected to a terminal board on the cover and also to ground. A protective choke coil, made of bare aluminum wire wound on a treated wood frame, is supported from the 150,000-volt terminal.

Pressboard collars and coil spacers insulate the high-voltage coils from each other and allow oil circulation. The main high-voltage coils are wound as single sections and connected alternately at the inner and outer edges.

Several coils at each end of each section are reinforced, the line coil being of heavily insulated copper strip, wound one turn per layer.

Voltmeter Coil

A coil of few turns, so placed as to embrace the same flux as the average turn of the high-voltage winding, will indicate the high voltage with great accuracy regardless of load or power-factor. The ratio of turns with the high-voltage winding is usually 1 to 1000 or 2000, thus reading direct in kilovolts or half kilovolts.

The usual impression seems to be that this coil will not be correct at low power-factors, but it should be obvious that there is at least one location in which the resultant flux linkage (main flux plus the leakage flux added vectorially) will be the same per turn of the voltmeter coil as for the average turn of the whole high-voltage winding so that it must read correctly, neglecting second order differences, which are negligible.

These differences, such as the resistance of the voltmeter coil and high-voltage winding and the distributed nature of the reactance, are extremely small. Tests show that the voltmeter coil indicates the induced high voltage with a greater accuracy than any other practicable method, that the difference between the induced and terminal voltage may be kept below ½ of 1 per cent, and that even the wave form is reproduced with great fidelity. Either the effective or crest value of the voltage may be read on suitable instruments, but it is not claimed that transients may be so measured. For these a ball spark-gap is universally used and connected through a resistance of ½ to 1 ohm per volt, directly across the high-voltage circuit.

Terminals

The high-voltage terminals were expressly designed for testing transformers and represent a distinct and original type. Relatively small size and high arcing voltage are essential for this work where extreme high voltage is coupled with low kilovolt-ampere capacity.

The terminals are of the semi-solid type. A steel tube is heavily insulated with shellac paper forming the core of the terminal. This is wrapped with black varnished cloth which is formed into flanges much as in the transformer itself.

The insulated core is inserted in a metal ground sleeve forming the supporting flange, and completed by the addition of the outer cylinder of shellac-paper and the hollow cast aluminum alloy cap. The whole is then given a vacuum treatment and filled with "vaseline" (petrolatum).

The central steel tube ends some distance from the lower end of the terminal and connection to the windings is made through a heavily taped connecting rod. The insulation thus extends from the cap clear into the windings so that the lower end of the terminal may be short and placed close to grounded metal.

The large radius cap permits close grouping and the final result of the design is that terminals of very high arcing voltage may be placed close together and close to the core or tank without danger of arc-over. Fig. 2 shows where the terminals are placed at the edge of the cover and close together. The arcing voltage is about 200,000 for the small terminal and 300,000 for the large one. When arc-over occurs, as in testing the terminal, it is not preceded by corona or sparking and the arc goes wide of the terminal, hence does no damage.

The terminal boards for the low-voltage winding, voltmeter coil, and grounded end of the high-voltage winding are of fiber with nickel plated brass unions.

General Characteristics

Round tanks are standard for single-phase and are relatively short, the depth varying from one to one and one-third diameters. Extra radiating surface when needed is provided by the addition of outside tubes.

All testing transformers are shipped oil-filled, and are made as nearly air and oil tight as possible by gaskets at every opening in the cover and close spacing of all bolts. The design is compact and it is seldom necessary to remove the terminals for shipment though all of the vaseline-filled type are designed for easy removal, without disturbing the internal connections.

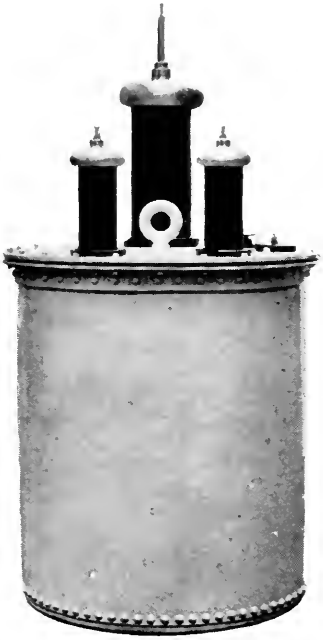

Fig. 2. 150-kv-a., 75,000/150,000-volt Transformer

The high-voltage coil stack is clamped and centered by set screws at each end passing through the flanges of the core channels. In the larger sizes additional support is given by cast iron or steel brackets held by the main core bolts.

Flux densities are moderate, to avoid wave distortion from the effect of harmonics in the exciting current acting through armature reaction in the generator. Ordinary generators may give good wave form at zero load but show bad distortion on small load if the exciting current contains a large proportion of third and fifth harmonics.

The internal capacitance of testing transformers of 100,000 volts and higher is so great and the magnetizing current so low that the exciting current is usually leading at all voltages.

The high-voltage conductor is seldom less than 0.010 in. in diameter, which is good for 0.1 amp.

It is difficult to wind large diameter coils with fine wire which is liable to mechanical injury and open circuits and is not suitable for the thick conductor insulation required for high dielectric strength between turns. Wire 0.010 in. in diameter might be used up to 150,000 volts, but larger wire would be used for higher voltages regardless of current capacity, for facility of winding and handling, mechanical strength, and better insulation possibilities.

The ability to put many turns in small space is of little advantage because it leads to a concentration of voltage too great to be safe, since the volts per turn is high. This requires subdivision of the winding into many narrow coils of little mechanical strength. At the higher voltages, the capacitance of the transformer itself plus that of the apparatus under test may take a charging current exceeding 1 amp. and in general, to allow for this, the current capacity should increase with the voltage at the rate of at least 0.1 amp. per 100,000 volts.

Since the current capacity of the high-voltage winding may exceed the normal rating and is preferably made high, a great increase in rating may mean little more than a large low-voltage conductor, which signifies little, and a higher reactance, which may be important. A 300-kv-a. 300,000-volt transformer is practically identical with a 150-kv-a. unit except for the reactance which may be double.

Grounding the middle point of the high-voltage winding halves the voltage stresses from winding to ground and reduces the size, weight, reactance, and cost. Grounding one end permits tapering the insulation from maximum to zero and eliminates one high-voltage terminal.

Full insulation with two high-voltage terminals represents the most inefficient and expensive construction and is seldom necessary.

The ratios of cost for the three forms are about:

Center grounded; 66 to 75 per cent
End grounded; 100 per cent
Ungrounded; 125 to 133 per cent.

Preferred Standard Ratings

Frequency; 60 or 50
Kilovolts; 30, 50, 100, 150, 200, 250, 300, 350
Amperes; $\frac{1}{10}$, ¼, ½, or 1
Supply voltage; 220, 1150, or 2300

If an induction regulator is used the transformer low voltage rating must be double the supply voltage.

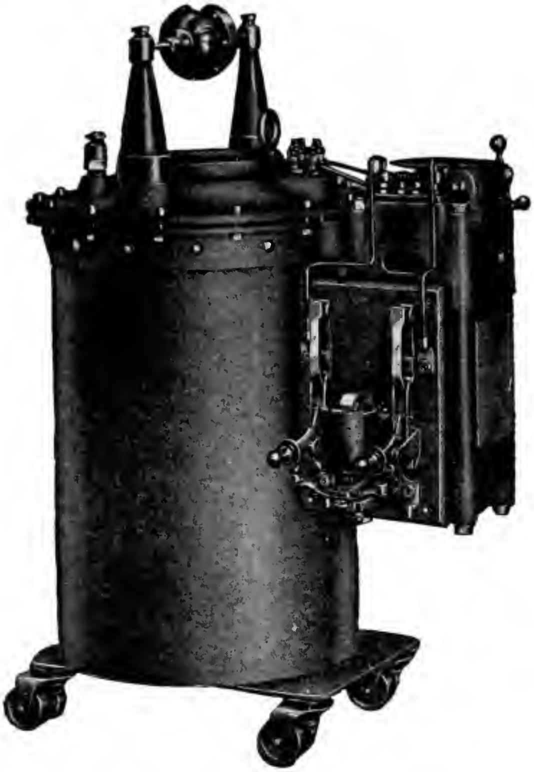

Fig. 3. Standard, Oil Testing Set

Testing transformers and auxiliary apparatus exhibit refinements in design, construction, and finish not usually associated with this class of equipment. Reliability is the most important requisite, but great care is taken to obtain simplicity, compactness, close regulation, low flux densities, good mechanical construction, and attractive appearance.

REPRESENTATIVE SIZES AND TYPES OF TESTING SETS

High-voltage, Alternating-current Sets for General Testing

The frontispiece of this issue of the REVIEW shows a general view of a series of sizes of testing transformers and auxiliary apparatus set up in the shop in which they were built. It includes the following:

3-kv-a. 30,000-volt oil testing set
5-kv-a. 50,000-volt Portable set
10-kv-a. 100,000-volt Laboratory transformer
7.5-kv-a. 75,000-volt Precipitator transformer
10-kv-a. 100,000-volt Precipitator transformer
150-kv-a. 300,000-volt Insulator testing transformer
6¼, 12½, and 25-cm. ball spark-gaps.

Oil and Insulation Testing Set

Fig. 3 represents a thoroughly standardized 60-cycle set, made in quantity and considered indispensable in all electrical installations of any magnitude. It consists of a 3-kv-a. 30,000-volt transformer, a 1-kv-a. induction regulator, giving the full range of voltage from zero to 30,000, and a standard oil testing spark-gap, removably mounted on the high-voltage terminals.

The high-voltage winding is entirely insulated so that tests may be made either with or without a ground connection.

A voltmeter coil gives accurate indications of the high voltage, which may also be determined approximately from a graduated dial on the regulator shaft, when the low-voltage is known, and the load small, as in oil testing.

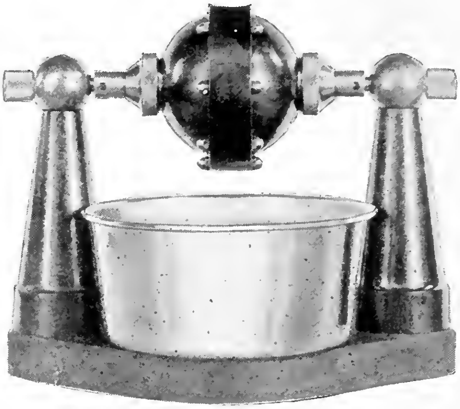

Fig. 4. Oil Testing Spark-gap and Stand

The whole outfit weighs about 500 lb. and is mounted on casters. It is not limited to oil testing, but the voltage, capacity, and reactance are suitable for a wide range of testing and experimental work about a power station, on generators, motors, other transformers, insulating material, rubber gloves, and so on.

The current capacity is not sufficient for testing cables except in short lengths.

Oil Testing Spark-gap

The oil testing spark-gap is shown in Fig. 4 mounted as a separate unit, which is sometimes convenient when operated from a transformer other than the standard oil testing transformer.

Fig. 5 shows the spark-gap alone. It is made in identical halves, each consisting of three pieces of simple symmetrical form and massive proportions. The body is turned from the highest grade of hard rubber plate and threaded to receive the adjustable studs forming the electrodes; flat, square-edged disks, 1 in. in diameter. Both studs and micrometer locking nuts have index marks. The pitch of the thread is 20 per inch and gap settings may be made from zero to 0.25 in. in steps of 0.05 in., the standard setting being 0.100 in. or two turns of the screw. The setting is determined by the index marks, no gauge being necessary.

This form of spark-gap is the result of long evolution and has been adopted as standard by the leading transformer manufacturers of the United States. It is anticipated that it will soon be officially adopted by the American Society for Testing Materials and possibly abroad also. It conforms to the requirements of the National Electric Light Association and the American Institute of Electrical Engineers.

The best form of spark-gap has been the subject of much discussion and elaborate comparative tests. It is generally admitted that the present standard combines the greatest number of desirable features and is the best in accuracy, sensitiveness, simplicity, reliability, and consistency of results.


Fig. 5. Oil Testing Spark-gap

5-kv-a., 50,000-volt Set

The next most popular size is shown in Fig. 6 mounted on a ball-bearing truck with regulator and circuit breaker. One end of the high-voltage winding is connected to the tank and but one high-voltage terminal is required. This is the usual arrangement for central station work where the apparatus under test is grounded.

A film cutout at the ground terminal permits the insertion of an ammeter directly in the high-voltage circuit.

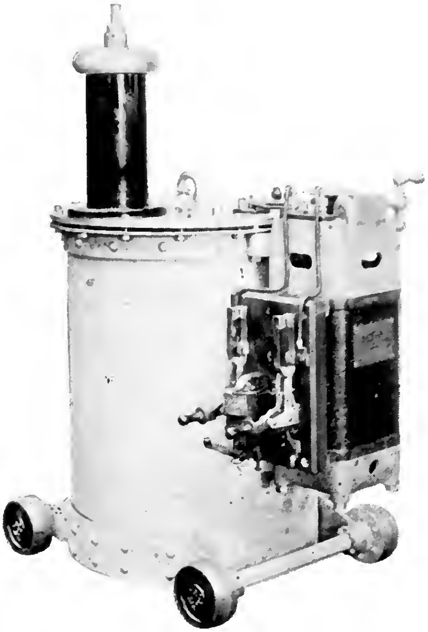
Fig. 6. 5-kv-a., 50,000-volt Portable Testing Set

10-kv-a., 100,000-volt Set

The unit shown in Fig. 7 has the middle point of the high-voltage winding grounded, which reduces the size and cost and permits the use of small treated wood terminals. It is especially suited for laboratory work or portable testing sets when small weight is an object and the apparatus or material under test may be insulated from ground.

7.5 kv-a., 75,000-volt Set

Fig. 8 shows an interior view of a unit originally built for operating a Cottrell precipitator, but it is essentially the same as a testing transformer, except that there is no voltmeter coil and the high-voltage winding is entirely insulated.

75-kv-a., 100,000-volt Set

Fig. 9 is of a unit of the same type, built for continuous operation with a tubular tank, oil gauge, and thermometer. The exterior is shown in Fig. 10.

50-kv-a., 100,000-volt Set

An interior view of a typical testing transformer of medium size is shown in Fig. 11. One end of the high-voltage winding is grounded through a film cutout. The domed cast-iron cover is sometimes used but it is suitable only for a definite number and size of terminals. Steel plate covers must be used for special designs.

Fig. 7. 10-kv-a., 100,000-volt Laboratory Transformer

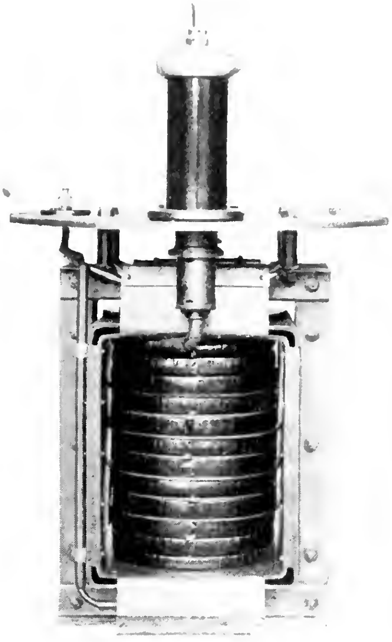

Fig. 8. 7.5-kv-a., 75,000-volt Transformer

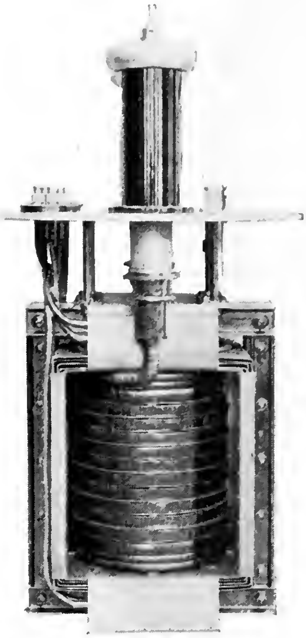

Fig. 9. 75-kv-a., 100,000-volt Transformer

150-kv-a., 250,000-volt Set

Several units, Fig. 12, may be connected in series for the higher voltages by the use of extra primary and secondary windings in each unit for exciting the next in the series. This scheme is known as the "chain connection" and is illustrated in Fig. 13. Fig. 14 shows one of the units, which externally can hardly be distinguished from an ordinary design.

Previous designs for series connection and excitation have given poor results because of excessive reactance, voltage instability, and low power in the high-voltage circuit. The present method overcomes these disadvantages in the following manner:

Each unit has, in addition to the main primary low-voltage and secondary high-voltage winding, additional primary and secondary exciting windings.

The exciting primary has the same number of turns as the main primary and is permanently connected in parallel with it. The exciting secondary has the same number of turns as the primary, but is located adjacent to the line end of the main secondary and the two have a common connection to the high-voltage terminal. The other end of the exciting secondary connects to an additional insulated conductor running through the high-voltage terminal. The lower end of the main high-voltage winding is connected to the tank through a film cutout.

The primary and secondary exciting windings are separated by the main high-voltage insulation, but are in close inductive relationship, so that the next unit in the series may be excited through windings of low reactance.

All the units are identical but the second and following units must be placed on insulating supports since the tanks are at successively higher voltages to ground.

The load on the exciting windings decreases through the series toward the high-voltage line, and the exciting windings of the last unit are not used.

Special features, not clearly shown, insure low reactance and protection from high-voltage transients.

This is a flexible and economical arrangement, enabling the use of a few comparatively small, low-voltage units for obtaining very high voltages, with one end or the center of the series connected to ground, as well as a three-phase connection with grounded neutral.

It is applicable particularly to testing sets of high voltage and low capacity.

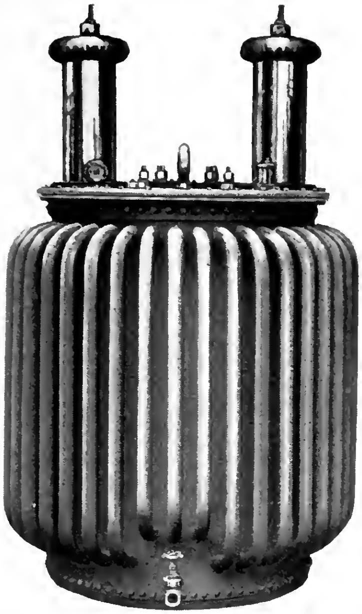

Fig. 10. Exterior of Transformer Shown in Fig. 9

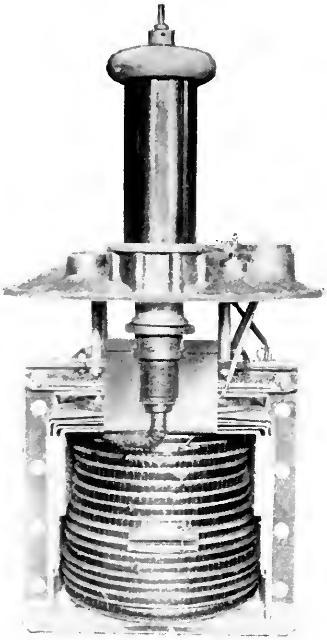

Fig. 11. 50-kv-a., 100,000-volt Transformer

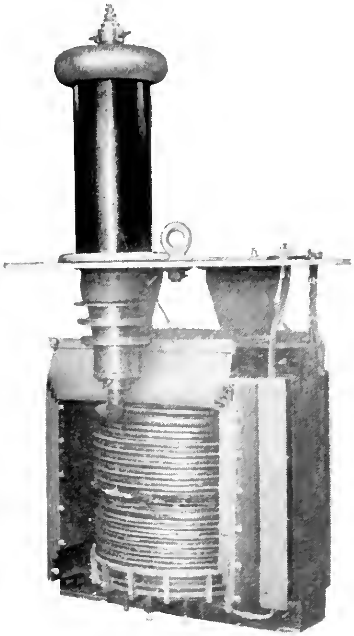

Fig. 12. 150-kv-a., 250,000-volt Transformer for "Chain Connection"

150-kv-a., 300,000-volt Set

The unit shown in Figs. 15 and 16 is of a popular size and type, much used for tests on line insulators and experimental work. One end of the high-voltage winding is grounded so that but one high-voltage terminal is required. The tank is 65 in. in diameter and 84 in. high over the cover.

The voltmeter coil is of the so-called differential form, wound partly inside and partly outside of the high-voltage winding. The errors of the two parts are of opposite sign and made to neutralize as nearly as possible.

500,000 Volts and Higher

Central stations seldom require voltages above 300,000 volts, although sometimes two 300,000-volt units are used in series with the neutral point grounded for obtaining 600,000 volts for tests on strings of suspension insulators.

Voltages over 300,000 volts are more easily obtained by the use of several 250,000-volt units in "chain connection" as already described. This has the advantage that operations may be begun with one 250,000-volt unit and the capacity of the testing set may later be increased by the addition of one or more 250,000-volt units to obtain three-phase combinations or voltages to ground up to 1,000,000.

The voltage to ground of any combination may be doubled by duplication of the apparatus so that eight 250,000-volt units could be operated in series with neutral grounded to give 2,000,000 volts between lines.

So far no reference has been made to the 1,000,000-volt, three-phase outfit of the Pittsfield Works of the General Electric Company as this was fully described in the *Journal of the A.I.E.E.* for October and November, 1922, and the GENERAL ELECTRIC REVIEW of December, 1922, and February, 1923*. However, it may be of interest to add some of the latest results obtained with this outfit.

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*Reprints of the G. E. REVIEW article are at present available by application for Reprint X-692.

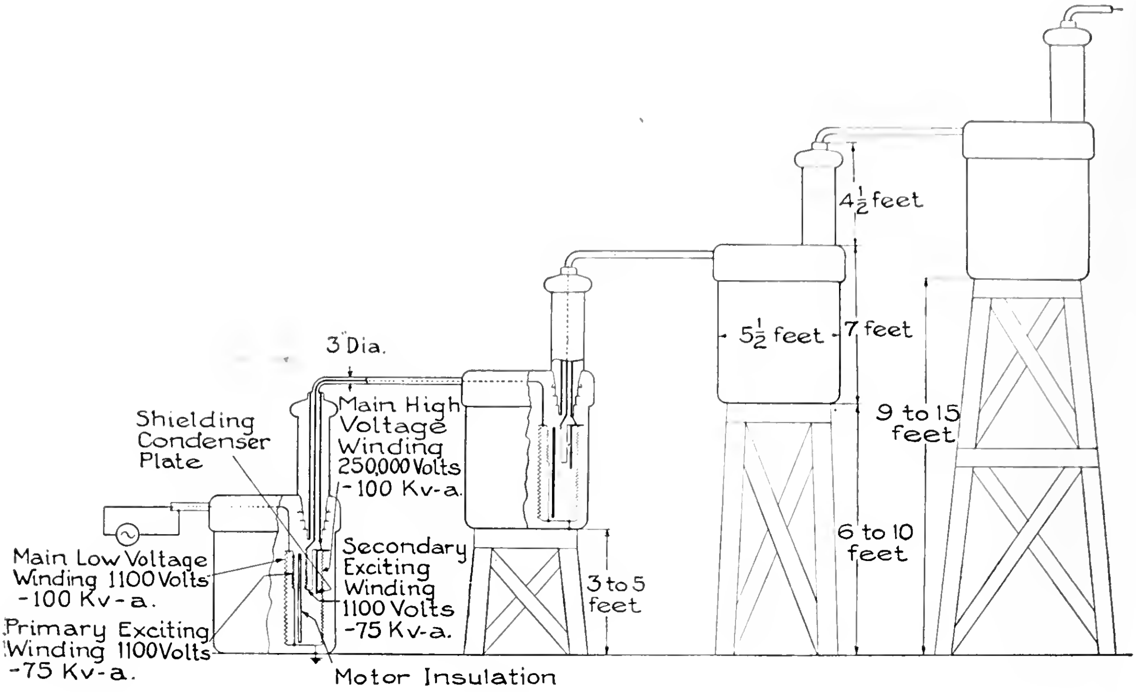

Fig. 13. "Chain Connection" for 1,000,000 Volts to Ground

Fig. 14. Exterior of Transformer Shown in Fig. 12

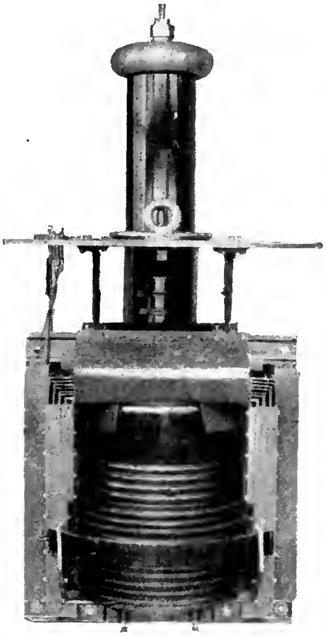

Fig. 15. 150-kv-a., 300,000-volt Transformer

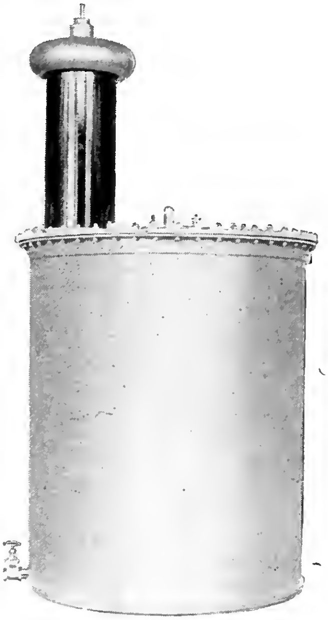

Fig. 16. Exterior of Transformer Shown in Fig. 15

Fig 17. Nine-foot, Million-volt Arc Photographed through a Glass Lens

Fig. 18. Same Arc as Shown in Fig. 17, but Photographed through a Lens made of Quartz produced in the Thomson Research Laboratory of the General Electric Company

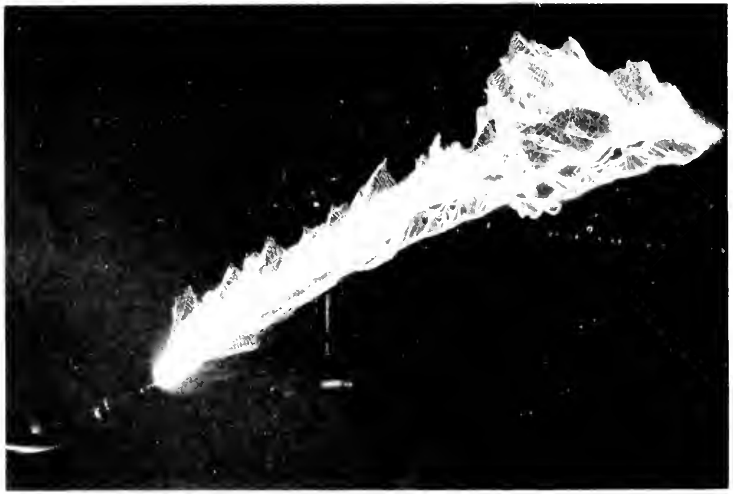

Fig. 19. Fourteen foot, One and one half Million-volt Arc, through Glass Lens

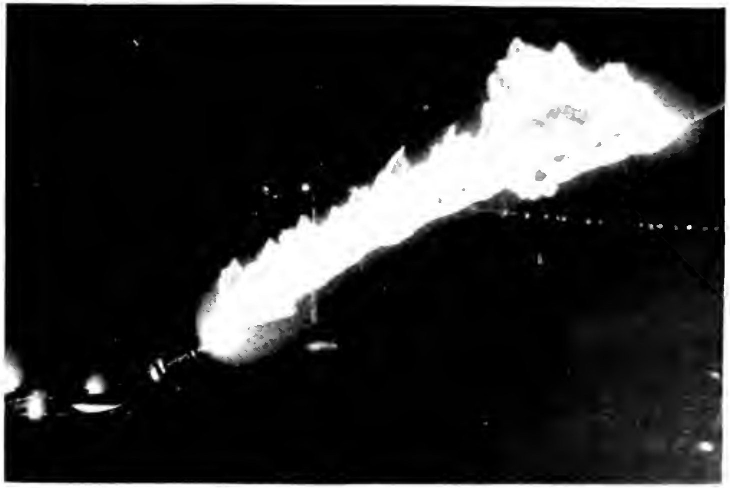

Fig. 20. Same Arc as Shown in Fig. 19, but Photographed through a Quartz Lens

Photographs of Arc and Corona taken with Glass and Quartz Lenses

Fig. 17 shows a nine-foot million-volt arc to ground between points as taken with a glass lens: and Fig. 18 shows the same arc taken through a quartz lens.

The glass lens, being opaque to ultra-violet rays, shuts off much of the corona but, being highly corrected, gives sharp defination. The quartz lens is transparent to ultra-violet rays, but being a simple lens cannot be corrected as with glass and gives a blurred effect.

Since quartz has uniform optical constants, it is not possible to combine several grades to neutralize the principal aberrations as is done with glass. Even so, a quartz lens is something like five times as fast as glass and transmits perhaps a thousand times as much ultraviolet light, extending the effective spectrum over double the range of visible light.

The quartz lens was made from fused quartz produced by the Thomson Research Laboratory of the General Electric Company at West Lynn.*

Fig. 19 represents a fourteen-foot arc between points at about 1,500,000 volts, taken with a glass lens. Fig. 20 is the same arc taken with the quartz lens. There is a great difference in the amount of corona shown on the choke coils mounted on the million-volt terminal.

The difference between glass and quartz is brought out in a still more striking manner by comparative photographs taken on a pinwheel, mounted on ball bearings on the top of the 1,000,000-volt terminal. The wheel is three feet in diameter, consisting of four aluminum wires with the ends bent tangent to the circumference of the wheel and pointed. When voltage is applied the wheel revolves at considerable speed from the reaction of the discharge from the points.

Fig. 21. 800,000-volt Corona, through Glass Lens

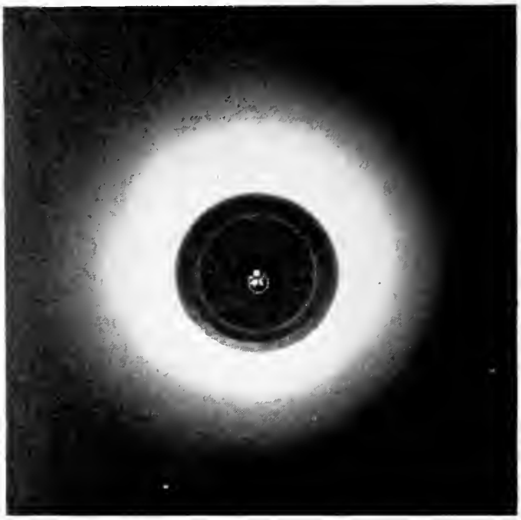

Fig. 22. 800,000-volt Corona, through Quartz Lens

Fig. 21 shows the corona as taken through a glass lens from a point 23 ft. directly above the wheel which revolves in a horizontal plane. The exposure was 15 seconds and the voltage 800,000.

Fig. 22 is of a photograph taken under the same conditions except that a quartz lens was used. The width of the band of corona is about five times as great as with the glass lens.

Fig. 23 shows a photograph of 900,000-volt corona taken through a quartz lens with the same exposure.

At low voltages the difference in the appearance of the photographs taken through glass and quartz lenses is considerable; but it was supposed that the difference would be much greater at the higher voltages and this is borne out by the photographs, which indicate that it is necessary to use a quartz lens in taking photographs of arc and corona phenomena if the whole effect is desired.

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*See article on "Silica Glass or Fused Quartz," by Elihu Thomson, G. E. REVIEW, February, 1923.

Fig. 24 is of 800,000-volt corona, taken through a quartz lens with an exposure of five minutes.

Alternating-current Cable Testing Sets

200-kv-a., 10,000-volt Set

Of relatively high capacity and low voltage, the unit shown in Fig. 25 is built in the interleaved disk coil type and is compact and of great simplicity.

40-kv-a., 26,400-volt Set

A portable set with induction regulator and switchboard all mounted on a truck with ball-bearing rubber-tired wheels is shown in Fig. 26. The transformer has a high-voltage winding in four sections with eight terminals.

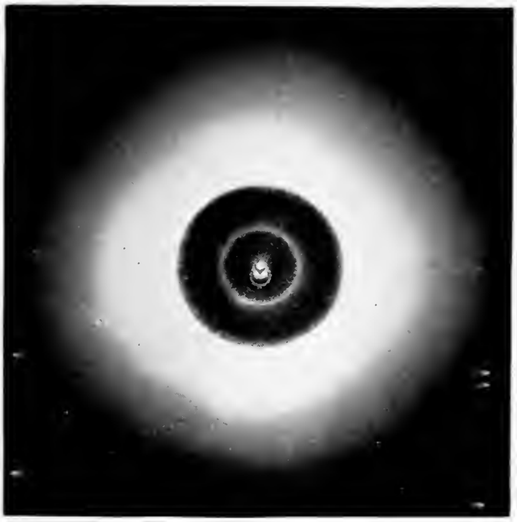


Fig. 23. 900,000-volt Corona, through Quartz Lens

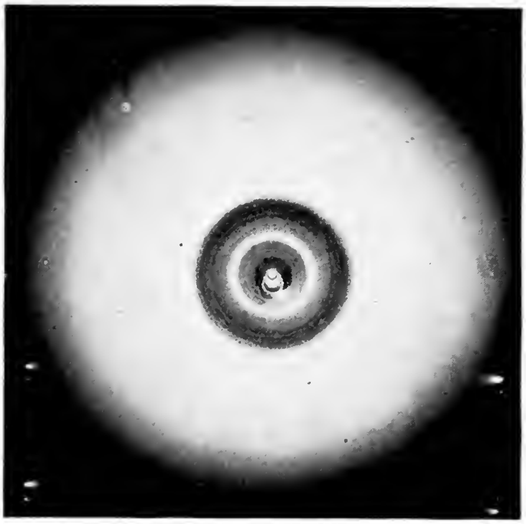


Fig. 24. 800,000-volt Corona, through Quartz Lens (5-minute exposure)

132-kv-a., 24,000-volt Set

An unusually elaborate set with two ball-bearing reels, each carrying 100 ft. of 24,000-volt cable, is illustrated in Fig. 27.

600-kv-a., 30,000-volt, 3-phase Set

The transformer shown in Fig. 28 is operated by a three-phase induction regulator. The series-parallel high-voltage windings require 12 high-voltage terminals.

2100-kv-a., 60,000-volt Set

The high-voltage winding of the unit shown in Fig. 29 is in two sections for series-parallel connection, one end being grounded through a film cutout. The conductor is of flat strip wound one turn per layer, the same as in a large power transformer. The core has air gaps for 50 per cent exciting current.

350-kv-a., 66,000-volt, Transformer with 1000-kv-a. Balancing Inductance

These two units, Figs. 30 and 32, are intended to be used together. The interior construction of the inductance resembles that of a transformer except that it has taps on the high-voltage winding and there is no low-voltage winding. The core has air gaps as previously described.

125-kv-a., 30,000-volt Transformer with 700-kv-a. Balancing Inductance

Fig. 31 is of a complete outfit in three units, each mounted on a roller-bearing truck. The inductance carries a ball spark-gap with series high resistance and an ammeter is mounted on an insulating post for direct insertion in the high-voltage line.

60-kv-a., 100,000-volt Set

The tank of the unit in Fig. 34 contains the main 60-kv-a. transformer and three filament transformers for heating the cathodes of four kenotrons mounted on the high-voltage terminals. The induction regulator, power

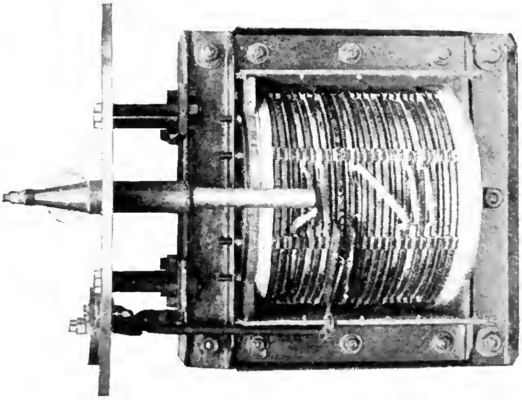


Fig. 25. 200-kv-a., 10,000-volt Cable Testing Transformer

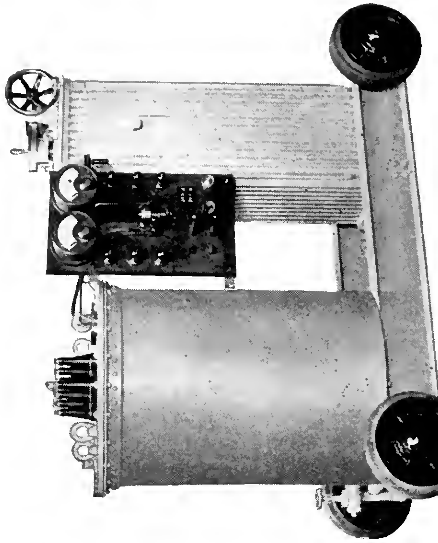


Fig. 26. 40-kv-a., 26,400-volt Cable Testing Set

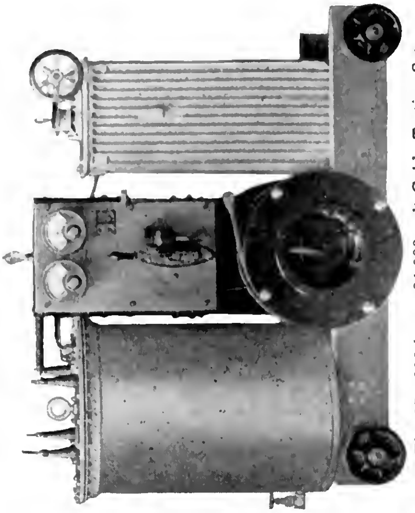


Fig. 27. 132-kv-a., 24,000-volt Cable Testing Set

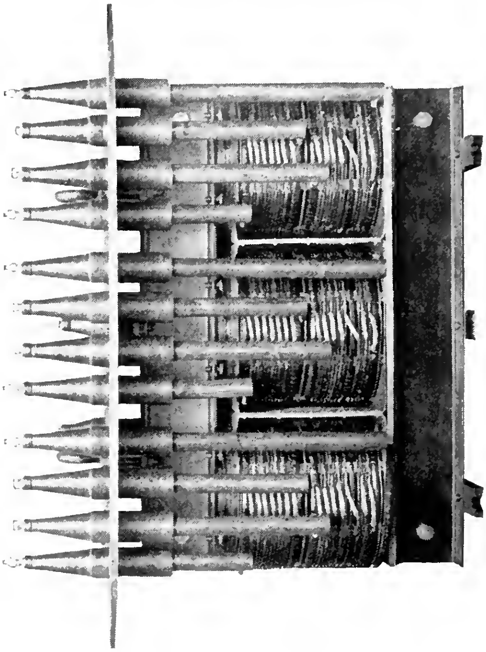


Fig. 28. 600-kv-a., 30,000-volt Cable Testing Set (removed from tank)

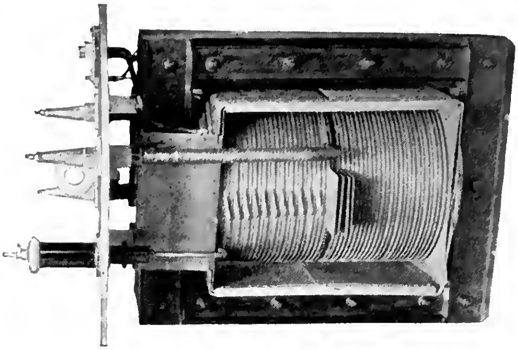


Fig. 29. 2100-kv-a., 60,000-volt Cable Testing Transformer (removed from tank). Air-gaps in core for 50 per cent exciting current

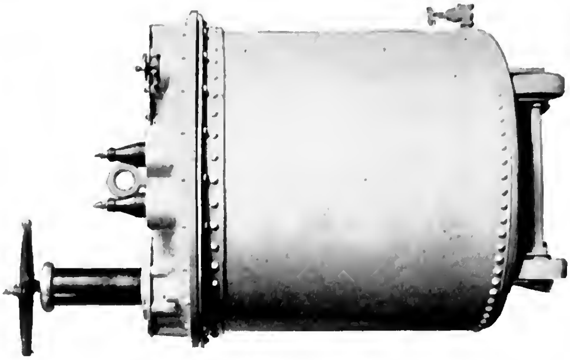


Fig. 30. 350-kv-a., 66,000-volt Cable Testing Transformer

limiting reactance, and three-panel switchboard are combined as a separate unit.

100,000-volt Filament Transformer

The illustration in Fig. 33 is from a drawing showing the cross-section of a standard design, insulated for 100,000 volts effective and intended for heating the filament of a kenotron in a direct-current cable testing set. The tank is 15 in. in diameter and the kenotron is mounted directly on the terminal in a vertical position.

Fig. 35 shows an outfit for an impulse generator for lightning arrester tests and includes a 100,000-volt transformer with four filament transformers and kenotrons.

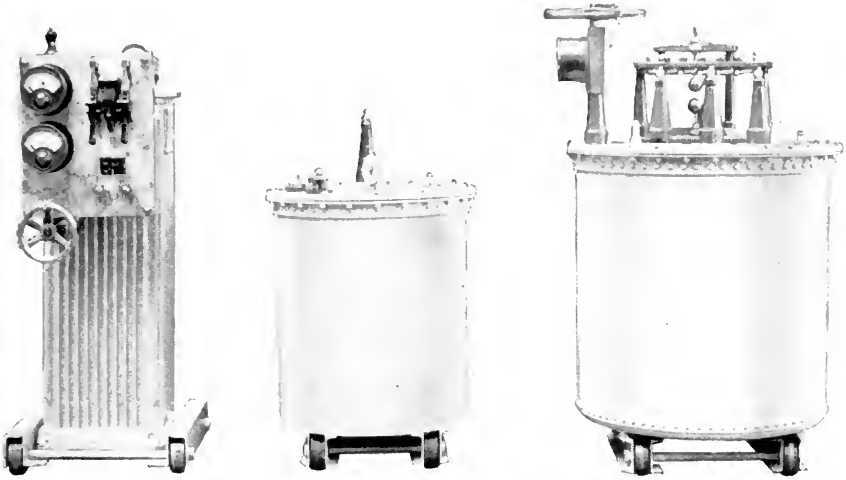


Fig. 31. 125-kv-a., 30,000-volt Transformer, 700-kv-a. Balancing Inductance and 62.5-kv-a. Induction Regulator

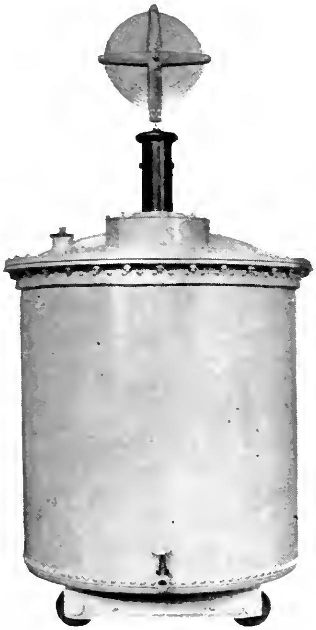


Fig. 32. 1600-kv-a., 66,000-volt Balancing Inductance

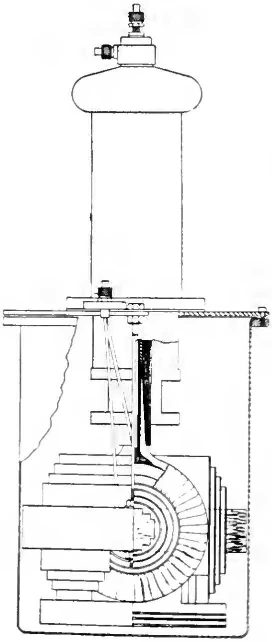


Fig. 33. ½-kv-a. Filament Transformer Insulated for 100,000 Volts

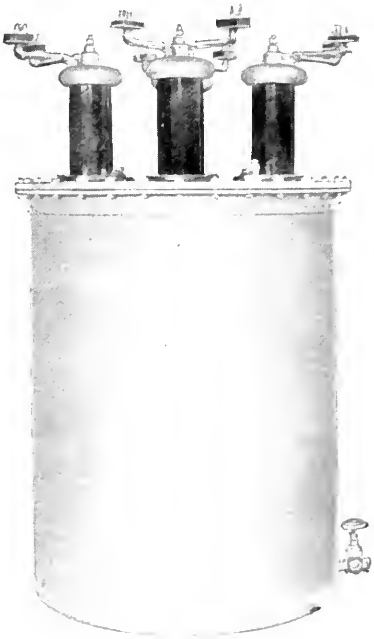


Fig. 34. 60-kv-a., 100,000-volt Direct-current Cable Testing Set

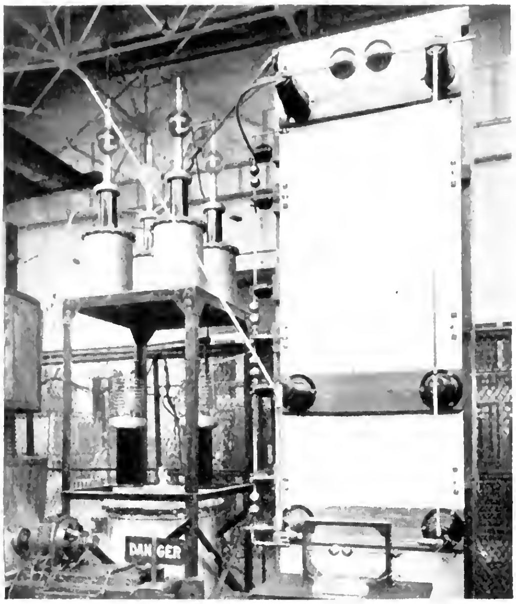


Fig. 35. 10-kv-a., 200,000-volt Direct-current Set for Testing Lightning Arresters

Auxiliary Apparatus

Ball spark-gaps for measuring the voltage have been standardized in sizes using 6¼, 12½, 25, and 50-cm. balls and suitable for 100, 200, 300, and 500 kv. respectively. A 50-cm. gap of the suspended type is shown in Fig. 36. This is now made with removable legs so that it may be suspended from insulators or stood on the floor as in Fig. 37.

Protective choke coils with parallel resistances are mounted on the terminals for the higher voltages. A coil 37 in. in diameter for 300,000 volts is shown in Fig. 38.

In testing a large number of small devices, up to 10,000 volts, it is convenient to employ insulated handles for the high-voltage leads, but the method is dangerous unless suitable precautions are taken.

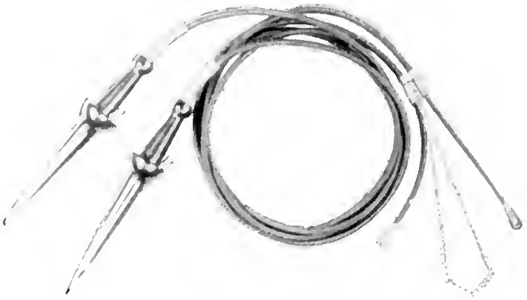


Fig. 39. 10,000-volt Safety Test Handles

Fig. 39 represents a pair of safety test handles showing great refinement of design and thoroughly safeguarded.

The cables have a complete outer sheath of fine braided wires which are connected together and grounded through the bronze chain shown attached to the ground clamp near the transformer terminal end. Each handle has a thumb-operated plunger switch with 10 breaks directly in the high-voltage circuit. This is normally held open by a spring and cannot be left closed. There is a complete grounded sheath between the operator and the high-voltage conductor, so that only the hardened tool-steel points are dangerous.

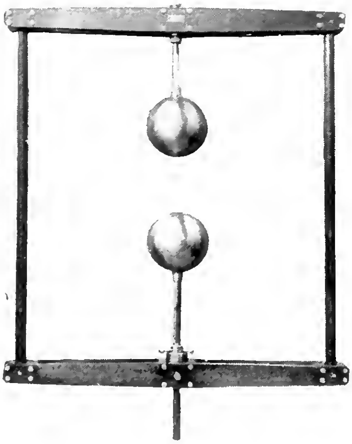


Fig. 36. 300,000-volt Spark-gap with 50-cm. Balls, Suspended Type

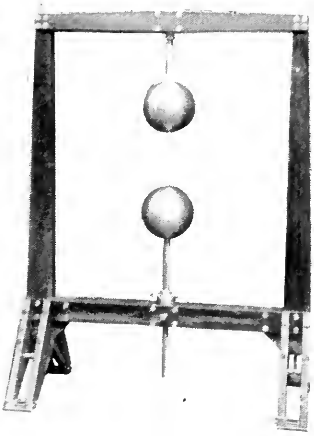


Fig. 37. 300,000-volt Spark-gap, Floor Type

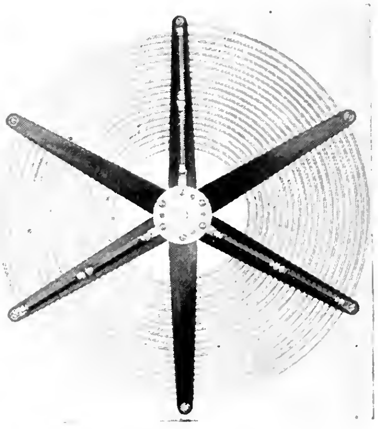
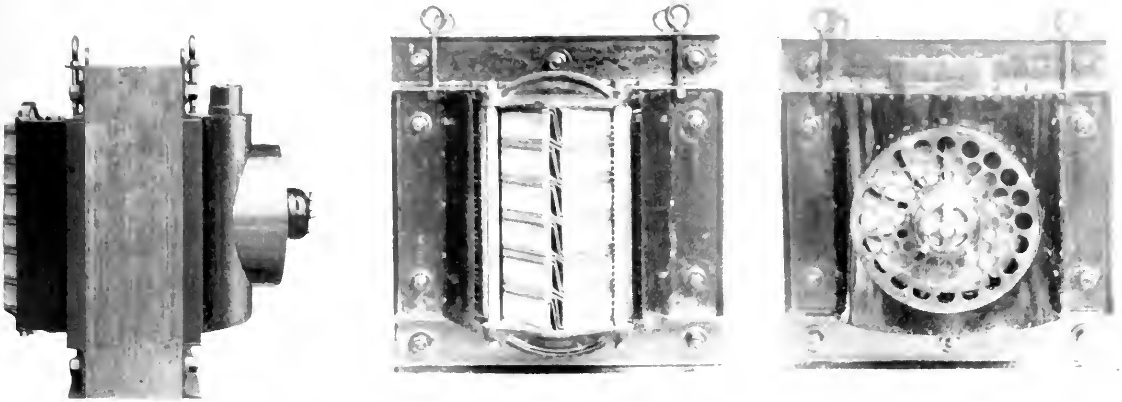


Fig. 38. 37-in. Protective Choke Coil for 300,000-volt Transformer



Figs. 40, 41 and 42. 250-kv-a., Air-blast High-current Transformer

High-current Testing

High current at low voltage is often required for tests on instruments, switches, busbars and other purposes.

Figs. 40, 41, 42 show a 250-kv-a. air-blast transformer with self-contained fan suitable for continuous operation. The low-voltage coils consist of 12 single turns, each sawed from sheet copper and without joints. One of these is shown in Fig. 44 and the complete low-voltage winding in Figs. 43 and 45.

The low-voltage coil may be connected in all series-parallel combinations giving from 132 volts 1900 amp. to 11 volts 22,700 amp. The changes are made by loosening the terminal yoke and shifting the bent connecting straps.

Several other sizes of the same style have been made and used for welding, resistance furnaces, and testing. The advantages of this type are the simple compact and economical construction, the great range of available ratios and ease of changing connections.

Conclusion

The examples given are of the more usual sizes and types of testing transformers, and those more or less standardized; but numerous and varied as they are, they represent but a small part of the endless variety that has been made and is constantly being increased. It would be tedious and take too much space even to illustrate the whole series of special designs, but enough has been presented to guide those who may be interested in such devices, but are unfamiliar with the course of development of a highly specialized branch of engineering.

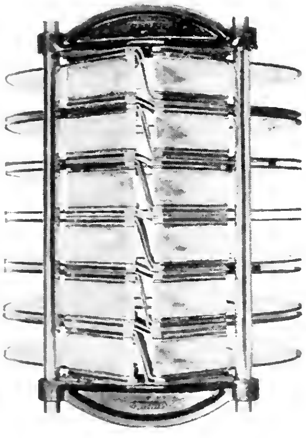


Fig. 43. Complete Low-voltage Winding of High-current Transformer

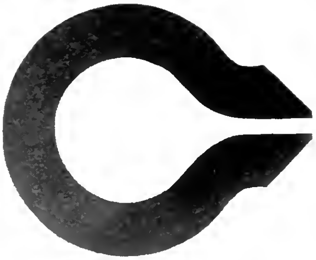


Fig. 44. Low-voltage Coil of High-current Transformer

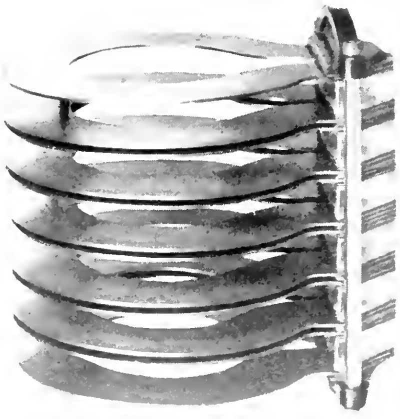


Fig. 45. Complete Low-voltage Winding of High-current Transformer

Sir Joseph J. Thomson's Address Before the Schenectady Research Laboratory

Sir Joseph J. Thomson's visit to Schenectady was noted in our May issue, on which occasion we published a photograph taken in the Research Laboratory of him and others. We now publish the brief address he made to the Research staff at Schenectady on the afternoon of April 6, 1923.—Editor.

Dr. Coolidge:

I am going to dispense with any introduction today, because our distinguished visitor can talk to us only about half an hour. He needs no introduction to us. There is no man in the world who less needs an introduction to the men and women here than Sir Joseph Thomson. Sir Joseph, the floor is yours.

Sir Joseph Thomson:

Ladies and gentlemen, I feel very acutely that the proper attitude of any visitor to this Laboratory is that of a learner, rather than a speaker. I have learned this morning very many interesting things that I did not know before, and I should like to have spent all my time learning, rather than in attempting to offer you something that I feel is not worthy of the occasion. But I thought perhaps it might interest you if I spoke first for a minute or two upon the efforts that we are making in England to imitate that movement of which you were the pioneers, and are the leaders, of the application of research to industry.

In my country there are difficulties about that, which do not exist here. In many of our industries there are not the important concerns that are capitalized to the extent of the very large firms in America. The backbone of the industry are firms, say, with a capitalization of some 200,000 to 500,000 pounds. Now it is clear that when the industry consists of units of that kind, the number of individual firms who can establish research laboratories on a scale that would promise important results cannot be very many. So the Government came in, and they established a body, of which I am a member, and placed very considerable sums of money at our disposal, and we go to the leading members of the industry and we say, "Won't you combine, and form a research laboratory for the whole industry? If you will do that, your Government will meet you and will pay pound for pound." Well, that has been a sufficient inducement for research laboratories to be established, and I think in between 25 and 30 different industries. We do not take any active share after these laboratories are started, in their management. We leave it entirely to the industry, and we say this—"It is up to you now that the thing has been started, to make it a success. We give you this grant for five years and then we shall come in and make a careful investigation of what you have done; and if you have done well, help will be continued if you need it."

Circumstances have not been very fortunate for the start, because when we started we started in a boom, and they could not get men. This was followed by a slump, and they could not get money. So we have had exceptional difficulties to contend with, but I think many of them, or a majority of them, have made good, and I imagine that they have become permanent institutions in our country.

Then again, we had to supply them with trained research workers. There were not enough men in the country, trained in research work, to man these laboratories, so that what we do now is, we say to the Universities, "If any of your graduates, or people who have just graduated, seem to you to be promising, promise to make good research workers, if they get the opportunities, then we will consider providing them with funds for two years' training in research under some Professor whom we approve." In that way we have been able to get a considerable number of men to be trained and to be available, either for these research laboratories, or for posts in Universities.

We have no lien upon their services afterward. If they choose, they are perfectly free after they have received these schoolarships for two years, perfectly free to do as they please. I think that movement has been successful now. We have almost a competent supply of properly-trained workers. This has only been going on for a short time, but it is, as I said, an attempt to keep up what has been successful in this country—the establishment of research laboratories in close connection with industries.

Well, that is a matter of organization. I won't say anything more about that, but I will try to speak about one or two things which have been happening in the Cavendish Laboratory recently, although I fear it is a poor showing, compared with the very interesting things which I saw this morning. But one thing that may interest you is the work of a young Russian who had escaped from the country and who came to us, and who has developed an old idea into a form which seems to me to promise very remarkable applications. I don't know if any of you have read Plante's original papers on the storage cell, but he in those papers describes a number of very interesting and simple experiments. He used to take two strips of ordinary lead and separate them by canvas, put them in a bucket, charge them up and then discharge, and get immense currents for a short time.

Well, that is the principle which Mr. Capietza has worked upon—the idea that if you used unprepared plates—plates of pure lead—they discharge with enormous rapidity, and so he builds up a storage cell. When it is completed it is not bigger than about the size of a cigar box. He has put a tremendous amount of work into it, so as to have the plates very near to each other, so that there is practically no internal resistance in this cell. Well, that cell is charged up until it is loaded, and then it is short-circuited and discharged. The time of discharge is only something less than 1/700th part of a second, and so you get the whole of the charge you put in discharged in this extremely short time. The result is that for a short time you get enormous magnetic fields, running up to several hundred thousand Gauss.

That little thing, about as big as a cigar box, will melt when it discharges, a copper rod about as thick as my finger. Well, I think that would probably have very important applications. It seems that the French military people have had something of the kind in their minds for a gun. You see you get a tremendous concentration of energy in this way in a small space; and I think the French have been proceeding on these lines and had this gun in their minds; but I do not know that anything has been done quite so convenient for physical purposes as this battery which Mr. Capietza has made, which is still in its early stages. The line on which he is working is by very careful workmanship to reduce the distances between the plates as much as possible, and have a very small internal resistance of the cell.

His view is that it is likely to have a very extensive application to producing Roentgen ray photographs for a doctor, to have this little thing which he charges at the nearest electric light station connected with an especially wound transformer or induction coil; and all that he would have to do would be to turn a handle. I don't know whether this will materialize or not, but it is evident to anybody who is interested in experiments on electrons or positive rays or anything of that kind, that the power to produce fields of this enormous magnitude is of great importance, especially when it can be done in such a simple way.

I ought to say that it would take very considerable labor and expense to make this battery, so as to get into it the workmanship good enough to produce the best results; but the body to which I have alluded before have taken it up and are financing it, and we hope to get it in a state in which it will be applicable for laboratories and can be applied to any case when we have to produce a very large magnetic field. When you come to think of it, generally when you want a very strong magnetic field you don't want it very long. You want it to deflect things moving very rapidly. Well if they move rapidly they don't stay long in a magnetic field, so that the strong magnetic field is only required for an infinitesimal time, and a little thing of this kind will furnish it.

In some experiments I have been doing myself, on the positive rays, I have been trying to get to the stage when you can do with a single flash for the positive rays, instead of producing a continuous discharge through the gas, and instead of using an induction coil, which keeps a discharge continuously going through the gas, to just use one flash. There is a great advantage in working with one flash instead of with a continuous discharge, because all kinds of complicated compounds are produced by the discharge itself. You see a great number of lines on your photograph which you have every reason to believe are compounds formed in consequence of a discharge passing through the gas. And so it is a matter of interest to try to get the conditions such that one flash would give you a photograph.

Well, a great deal depends upon properly designing the coil. I was sorry to find when I came to consider the question of design, that the best coil would be a very expensive instrument. But there is one point, that you can do something with ordinary coils—and that is that you must, to get the best results, reach a certain rapidity in breaking the circuit. After you get that, you don't get any benefit. So I set to work to try to get the break to work fast enough to give the best results. I tested this by Lord Rayleigh's device. I don't know whether you have ever employed it here. You break the circuit by simply firing a bullet from a revolver through a fine wire. That gives a very sharp break, and I took that method for testing whether I got my break up to the required standard. It is not convenient in a laboratory to fire these revolvers and break these wires, and when I got a mechanical break to do as well, I was very glad to employ that, instead of indulging in this shooting.

Well with that arrangement, I have not got it yet to the stage when I could get a photograph with one flash. I am sure it could be done by designing an induction coil of the right size, but what I have done I think is equivalent to it. I have a stream of the pure gas I an investigating flowing through the thing. I take one discharge and then I let it go on and flow for a time, and leave five or ten minutes between each flash, and so give the gas that is in the tube time to get washed out between the two; and I can get photographs with about eight flashes. Now these photographs are very interesting, entirely different (when I say entirely different, they look entirely different) from the photographs you get when you allow discharge to pass through continuously. For example, I took one with Benzine vapor flowing through the tube, and it gave an unusual spectrum. There was the atom of Hydrogen; there was the atom of Carbon; there was the molecule of Carbon; there was a compound of three atoms of Carbon, C_3. There was C_4, and there was C_5, and that was all. If I had taken a continuous discharge, I would have got probably fifty or sixty or more lines of all kinds of compounds of Carbon with Hydrogen; but when you take the flash and just deal with the molecules of the gas put into the tube, you get much simpler results, and results which are much more easily interpreted.

Then again, I tried to test views about chemical compounds, by means of these positive rays. You know that the Oxygen atom has 6 electrons in the outer layer. Nitrogen has 5. Now if you take a positively electrified Oxygen atom, which has lost an electron, it has 5 outside. Therefore, the positively electrified Oxygen atom would have an outer layer very similar to the neutral Nitrogen atom. Now when a neutral Nitrogen atom combines, you get a compound with three atoms of Hydrogen; and I wanted to see whether if you take the positively electrified Oxygen atom, which has five electrons, and therefore room for three more, whether you would get a compound containing three Hydrogen atoms to one Oxygen. Well, trying this experiment, I did. There is a line on the plate corresponding with a molecular weight of 19. It is a very common line, whenever you spark through a mixture of Oxygen and Hydrogen. Well then, I thought I would try to go one better.

You can get Oxygen atoms which have lost two electrons—that is, carrying a double charge. In that case you see you only have four electrons left, and they ought to correspond to neutral Carbon atoms. Neutral Carbon atoms can link up with four Hydrogens, and I wanted to see whether the doubly positively electrified Oxygen atom could link up with four Hydrogens, too. Well, on giving a long exposure, I found evidence of a line for which M/e was equal to 10. You see the charge is doubled, so M/e being equal to 10 meant that M was equal to 20, or about 16 plus 4, so that corresponds to a compound of Oxygen with four Hydrogens. There was no Neon in the tube, and no line for which M/e equals 20. The only line seen was M/e equals 10. And so you see the essence of this proof is that you only get the 4 Hydrogens when you have taken 2 electrons out of the Oxygen, so that it is only the doubly-charged ones that will exist in the combination represented by the compound OH_4.

Then there is another test—suppose you take an atom like Neon. Neon has eight electrons, and therefore does not combine with hydrogen; but suppose you pick out one—you can get positively electrified Neon atoms with the greatest ease, and these are the Neon atoms that have lost one electron and have seven left. They are like neutral Fluorine atoms and might be expected to combine, therefore, with one atom of Hydrogen. Mr. Aston, who has worked a great deal with Neon, has several plates in which there is a line corresponding to M equals 21—that is, 20 plus 1, of which the only interpretation seems to be that it is this compound of Neon and Hydrogen. I think there is a lot of interesting work to be done on these inert elements.

I do not believe that inert atoms are inert if you electrified them. If you knock off some of their electrons, I think it quite possible to find lots of compounds of the inert gases with the others. Most of them, of course, would be electrified and not of much use to you, because an electrified molecule cannot exist in a free state. But it is quite possible that you might get some one that is not electrified. The line on which I am trying to work is—suppose you have Neon positively electrified, its atom has, say, seven electrons. And then take the Oxygen negatively electrified atom—you can get Oxygen electrons negatively electrified—this will have seven electrons. Then you will have the Neon with seven and the Oxygen with seven also. They will be almost like two Fluorine atoms, and possibly they may combine. I don't know whether they will or not. I haven't got it yet, but I hope to have another try at it.

Then I have been trying to apply the method of positive rays to determine the nature of any charged atom—whether it occurs with the positive ray or not. For example, what was in my mind was to get some method that will tell you if there are any ions when chemical combination is going on at low pressure, or in combustions, to have some way of applying the method to gases where the ionization was not produced by electrical discharge.

It seems an easy enough thing—one sees how to start, anyhow. You let these combinations, whatever they are, go on in vessels raised to very high potential, and have a little hole in the vessel and a stream of gas flowing through. Just in front of that you have a perforated tube at a low potential, corresponding to the perforated cathode of the positive ray tube, and you get enough fall of potential to make the ions go along the narrow tube, so as to move in a definite direction.

Well, there came to be a good many practical difficulties in this work. I could not get it to work with photographic plates. We got no traces of lines on the plates. I got, however, results when I replaced the plates by a Faraday cylinder. I only had it working two or three days before I left Cambridge, and I only applied it to test whether the thing was working or not. I took the positive column in a discharge at high pressure and squirted out the gas from that and examined it, and found that in the positive column there are, as far as I can see, no negatively electrified ions. There are electrons, of course, but I could not detect any negatively electrified ions.

I don't want to lay too much stress upon that, because, as I said, I only got the method to work two or three days before experimenting with it. It is possible that a more careful study of experiments might reveal the existence of some of these negative ions, but I think they are very small in comparison with the positive. But when we get the thing working it will be capable of a great many applications, to determine the nature of the carriers of positive electricity under all kinds of circumstances. I think if we once get this thing properly schemed and arranged that it will be capable of attacking a good many questions of considerable interest, and I think now it has got to the stage where there is no doubt that it will work.

Well, I am afraid that I have detained you longer than the half hour, but I cannot sit down without expressing my very profound admiration for the work that is being done here. It seems to me there is greater density of interesting things in this building than in any other building with which I am acquainted; and I am very grateful to you for giving me an opportunity of seeing them.

Dr. Coolidge:

I cannot possibly express to you, Sir Joseph, the love and admiration we all feel for you, but I can thank you as I do, most heartily, for giving us this chance to see you and hear you. We hope that you will come again, and come many times.

Power Developments in Japan

By W. W. Lewis

Lighting Department, General Electric Company

Japan has in 70 years changed from a feudal state to one of the World Powers. Her influence is extending. She is trying to maintain what was good in the "old order of things" and at the same time to adopt the most useful features of occidental civilization. Her industries are increasing. Mr. Lewis recently made an extended visit to Japan and tells of her electrical developments.—Editor.

The leaders of Japan have a fascinating problem. Theirs is the problem of superimposing on the old Oriental civilization the most useful features of the modern Occidental civilization. This has resulted so far in retaining largely their own mode of living, habits of thought, religion, and system of ethics, and of adopting the mechanical facilities of Western nations. In time the mode of living of a large part of the population is bound to be affected, as Japan gradually changes under the stimulus of its mechanical and electrical development from an agricultural to an industrial nation. This transformation is inevitable and unescapable owing to Japan's resources in water power and lack of other natural resources, its geographical position and the necessity of competing with other industrial nations. Nevertheless, such a transformation will bring with it many evils known to Western nations and from which Japan has heretofore been free, such as conflicts between labor and capital, a congestion of population in the large cities, and a breaking down of the present family system. It is sure to change the political life of the country as the workers become self-conscious and demand a share in the government. The influence of the industrial era together with that of other Western innovations, such as the movies and the dance, will in time affect the character of the people, and it is only to be hoped that they do not lose too many of the characteristics which at present differentiate them from other peoples, that is the politeness, courtesy, and the general charm of their home life.

Fig. 1. Map of Japan, showing the Principal Transmission Lines in the Tokyo, Nagoya-Osaka, and Kyushu Districts

One of the Western facilities which was adopted first in a small way has now grown to tremendous proportions, that is the electrical industry. About one out of every three houses in the Kingdom uses electric light (although the per capita consumption is not large) and the small home industries use electric power to a large extent. Large industries, such as shipyards, steel plants, collieries, spinning mills, breweries, bakeries, etc., make extensive use of electricity and the industrial operations are being rapidly extended in all directions as more and more power becomes available.

Topography and Climate

The topography and climate of Japan are such that immense water-power resources are available. On the main island, named Hondo, mountains run through the country from one end to the other. In the central part are the Japanese Alps, with numerous peaks having altitudes of 5000 to 12,000 ft., and in some cases covered with perpetual snow. The rainfall and snowfall in these mountains are copious and the rivers numerous. The distance from the source of the rivers to the sea is in most cases short, so that the drop is quite rapid. This results in a large number of sites for small or moderate size power plant developments. The run-off varies of course throughout the year, being smallest in the winter months. As a rule, there is no great amount of storage capacity, so that the hydroelectric developments will naturally be accompanied by considerable steam development for stand-by service.

Power Available

There are three principal industrial districts on the island of Hondo; namely, the Tokyo district comprising Tokyo, Yokohama, and vicinity; the Nagoya district; and the Osaka district comprising Osaka, Kobe, Kyoto, and vicinity. The two latter districts are already tied together in a common power network, and according to plans under contemplation the Tokyo district will be connected to the others in the near future. Unfortunately, the frequency in the Tokyo district is 50 cycles while that in the others is 60 cycles, and this will present an obstacle in the way of free interchange of power between these districts. The island of Kyushu to the south also has a well developed power and industrial district, and in Taiwan (or Formosa) a large power project is being developed. It is difficult to obtain accurate or complete data on the power possibilities in any country and Japan is no exception. However, the following data are from reliable sources and as far as they go are believed to be quite authentic.

According to statistics prepared by the Department of Communications of the Japanese Government, there is available in the whole of Japan about 10,000,000 kw. of hydroelectric power. Of this amount about 7,000,000 kw. is to be found on the main island (Hondo). It is estimated that about 1,500,000 kw. of this power is not economically capable of development. This leaves 5,500,000 kw. that can be economically developed. Of this amount about 4,650,000 kw. is distributed on the rivers of Central Japan, within transmission distance to the Tokyo, Nagoya, and Osaka districts. This power is divided as shown in Table I. Of these rivers, the last named 11 with an aggregate capacity of 2,900,000 kw. are considered to have the most economical sites for power development, and of these rivers all except the Kurobe, Kumano and Yodo are either in operation or in some stage of development.

TABLE I

POWER AVAILABLE ON THE RIVERS OF CENTRAL JAPAN

River	Kilowatts	River	Kilowatts
Abukuma	200,000	Kiso	500,000
Tone	500,000	Kurobe	200,000
Sagami	150,000	Jintsu	250,000
Sakai	70,000	Sho	150,000
Fuji	150,000	Tetori	100,000
Ohi	150,000	Kuzuryu	100,000
Akano	500,000	Kumano	120,000
Shinano	750,000	Yodo	130,000
Ara	60,000	Hida	70,000
Hime	100,000	Others	30,000
Tenryu	300,000		
Yahagi	70,000		4,650,000

In Tables II, III and IV are given a list of the principal hydroelectric power systems in operation and under construction, from data compiled by the Department of Communications in November, 1922. The output in these three districts may be summarized as follows:

Tokyo District	241,500 kw.
Nagoya and Osaka Districts	197,500 kw.
Kyushu District	62,200 kw.
	501,200 kw.

This is less than ten per cent of the power available. These figures change from month to month as new projects are begun, but they are sufficiently close to give an idea of the present stage of development. In Taiwan (Formosa) there is a development under way by the Taiwan Electric Power Company involving at present about 110,000 kw. The intensive manner in which the rivers are being developed is illustrated by the installed and

TABLE II

TOKYO DISTRICT

Name of Company and Length of Transmission	Operation Started	POWER STATIONS		Output in Kw.	SUBSTATIONS		Trans-mission Voltage	Fre-quency Cycles
		Name	Elev. in Ft.		Name	Min. Elev. in Ft.		
Tokyo Electric Light Co. (175.2 miles)	Nov. 25, 1889	Tonosawa	1700	3,300	Hodogaya	165	44,000	50
	Oct. 1, 1892	Oshino	3260		Tozuka	165		50
	Apr. 1, 1922	Kanegafuchi	2300	2,390				50
	July 5, 1913	Shishidome	1840	18,800			77,000	50
	Sept. 11, 1920	Yamura	2540	13,500				50
	Aug. 26, 1912	Yatsusawa	1510	35,000	Yodobashi	165	55,000	50
	Nov. 15, 1922	Fuefukigawa	3160	No. 1, 2,800				
				No. 2, 2,800	Waseda	165	55,000	50
				No. 3, 3,000				
	Sept. 14, 1915	Iwamuro	2860	10,800	Sumida	165	66,000	50
	Feb. 9, 1921	Minowa	3010	4,600				
	Dec. 28, 1911	Kifune	1725	500	Ichikawa	165	66,000	50
Inawashiro Hydro Electric Co. (142 miles)	Nov. 12, 1914	Inawashiro	1970	No. 1, 37,000	Tobata	165	115,000	50
				No. 2, 24,000				
Kinugawa Hydro Electric Co. (103.9 miles)	Dec. 23, 1912	Taki	1260	1,000	Ogu	165	66,000	25
	Feb. 19, 1913	Shimotaki	1260	31,200				25
*Shinetsu Denryoku K.K.		Nakatsugawa	1350	18,000	Kameido	165	154,000	50
*Gumma Denryoku K.K.		Kanai	1480	4,430	Kawasaki	165	110,000	50
*Keihin Denryoku K.K. (125.5 miles)		Mimunegawa						
		Tatsushima	2840	8,479	Yokohama	165	154,000	50
Fuji-gas Spinning Co. (71.4 miles)	Sept. 28, 1912	Mine	2050	5,000	Komazawa	230	66,000	50
		Yamakita	773	5,600				50
		Uchiyama		3,350				50
Tokyowan Reclamation Co.	Mar. 16, 1917	Ochiai	1710	6,000	Kawasaki	165	66,000	50
				241,549				

TABLE III

NAGOYA AND OSAKA DISTRICTS

Name of Company and Length of Transmission	Operation Started	POWER STATIONS		Output in Kw.	SUBSTATIONS		Trans-mission Voltage	Fre-quency Cycles
		Name	Elev. in Ft.		Name	Min. Elev. in Ft.		
*Toyamaken.		Shomeigawa	3160	No. 1, 4,000	Fushiki	165	44,000	60
				No. 2, 1,900				
*Tateyama Hydro Electric Co.		Shirahagi		1,400				
		Nakamura	3070	3,000	Fushiki	165	22,000	60
*Azumi Denki K.K.		Saigawa	2370	2,400	Matsumoto	1930	22,000	50
Ina Denki K.K.	July 21, 1913	Otagiri	3820	1,350	Ono	3300	22,000	50
Tenryugawa Hydro Electric Co.	May 31, 1921	Toyone	2250	3,450	Hamamatsu	132	33,000	50
Yohagi Hydro Co.	Feb. 28, 1921	Shimomura		4,200	Toyohashi		33,000	60
	July 13, 1922	Oshiyama	2030	2,500	Okazaki	316	77,000	60

* Plants under construction.

TABLE III (Continued)
NAGOYA AND OSAKA DISTRICTS

Name of Company and Length of Transmission	Operation Started	POWER STATIONS Name	Elev. in Ft.	Output in Kw.	SUBSTATIONS Name	Min. Elev. in Ft.	Transmission Voltage	Frequency Cycles
HayakawaDenryokuK.K.	Dec. 7, 1906	Tomoegawa	1550		Hamamatsu	165	33,000	60
Okazaki Dento K.K. (35.4 miles)	Dec. 3, 1919	Tomoegawa	1230	1,565	Okazaki	316	34,500	50
Daido Denryoku K.K. (140 miles)	May 20, 1920	Okuwa	3200	11,000	Nagoya	165	77,000	60
	July 13, 1922	Suhara		9,200				60
	Sept. 4, 1919	Shizumo		14 700	Nagoya		77,000	60
	Sept. 1922	Yomikaki	1475	40,000	Furukawa-bashi	165	154,000	60
Toho Denryoku K.K.	Nov. 30, 1911	Yaozu		7,500	Nagoya	165	60,000	60
*Hakusan Hydro Electric Co.		Nishikatsuhara	2720	15,000	Sekimachi Switching Station	516	77,000	60
*Nohi Denki K.K.		Nagashima	2020	3,910	Gifu	454	33,000	60
Ibigawa Denka K.K.	July 21, 1921	Higashi Yokoyama	1800	12,000	Ogaki	165	77,000	60
	Oct. 1, 1915	Nishi Yokoyama	1800	3,900	Ogaki	165	44,000	60
*Nippon Denryoku		Seto	2220	21,000	Osaka	165	154,000	60
Tsu Dento K.K. (27 miles)	Aug. 25, 1910	Minowa	1360	700	Tsu	132	22,000	50
Kyoto Dento K.K. (100.3 miles)	Jan. 18, 1910	Kuroda	2080	800	Kyoto	457	15,000	60
Ujigawa Denryoku K.K.	Aug. 1, 1913	Uji	790	32,000	Osaka	165	55,000	60
				197,475				

TABLE IV
KYUSHU DISTRICT

Name of Company and Length of Transmission	Operation Started	POWER STATIONS Name	Elev. in Ft.	Output in Kw.	SUBSTATIONS Name	Min. Elev. in Ft.	Transmission Voltage	Frequency Cycles
Toho Denryoku K.K. (227.4 miles Total net work)	Nov. 1, 1897	Kawakamigawa	1460	6,600	Fukuoka	165	66,000	60
					Nagasaki	165	66,000	
					Omuta	98	25,000	
Kyushu Hydro Electric Co. (429.4 miles Total net work)	July 1, 1898	Onagobata	1410	15,000	Omuta	98	66,000	50
					Kurosaki	98	66,000	
					Takenoshita	165	66,000	
	Oct. 13, 1914	Shinohara	658	2,000	Kizuki	66	66 000	60
					Saganoseki	165	66,000	
	July 9, 1920	Jikuaru	1210	6,600				50
Kumamoto Electric Co. (154.5 miles Total net work)	July 1, 1891	Kikuchigawa	1300	No. 1, 980	Omuta	98	66,000	60
				No. 2, 1,490				
	Aug. 20, 1919			No. 3, 2,000				
NipponChisso-HiryoK.K. (55 miles)	Jan. 17, 1917	Naidaiji	1560	2,450	Kagami	98	66,000	50
		Midorigawa	1280	4,700				
		Shirakawa	1950	6,400				
		Sendaigawa		9,200				
		Sogi		4,770				
				62,190				

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* Plants under construction.

proposed plants of the Daido Electric Power Co. on the Kiso River. According to the plans, 16 plants will utilize a total head of 3464 ft. in a distance of about 75 miles.

During the present year there will be five systems in operation at 154,000 volts; namely, the Shinyetsu, Keihin, Nippon, Daido, and Taiwan Electric Power Companies. In the future it may even be necessary to go to 220,000 volts for some of the large power developments contemplated.

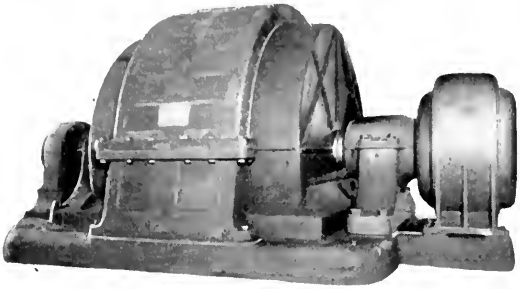

Fig. 2. Synchronous Condenser Rated 25,000 kv-a., 600 r.p.m., 11,000 Volts, for Nippon Electric Power Co.

The pioneer high-tension system is that of the Inawashiro Hydroelectric Co., which began operation at 115,000 volts in 1914. Aside from this, and the Gumma Electric Power Company which will operate at 110,000 volts, 66,000 and 77,000 volts are the most prevalent and popular.

Where Power is Used

The power supply or the three principal districts (which it is estimated require about 70 per cent of all the power demand on the main island) was in June, 1922, approximately as given in Table V.

TABLE V

	Steam Power Kw.	Water Power Kw.	Total Present Supply Kw.
Tokyo District . .	15,000	200,000	215,000
Nagoya District. .	10,000	60,000	70,000
Osaka District . . .	130,000	50,000	180,000
	155,000	310,000	465,000

According to statistics prepared by the government, the annual rate of increase of power demand since 1911 is about as shown in Table VI. Using this rate of increase of power demand, the total requirements for five years and ten years hence may be found in Table VII and Fig. 3.

TABLE VI

Tokyo District	20,000 kw.
Nagoya District	10,000 kw.
Osaka District	20,000 kw.
	50,000 kw.

TABLE VII

	Present Supply Kw.	Total Requirement at End of Five Years Kw.	Total Requirement at End of Ten Years Kw.
Tokyo District. . .	215,000	315,000	415,000
Nagoya District. .	70,000	120,000	170,000
Osaka District . . .	180,000	280,000	380,000
Total requirement	465,000	715,000	965,000
Total increase . . .	. . . .	250,000	500,000

Assuming that this is 70 per cent of the total requirement on the main island, the total for the main island ten years hence will be 1,375,000 kw. Assuming that the total for the main island is 67 per cent of the total for all Japan, the requirement for the whole of Japan will be 2,050,000 kw. At the present time approximately 67 per cent of the power is furnished hydroelectrically. In the future, this figure will probably be nearer 80 per cent, that is, in the neighborhood of 1,600,000 kw. will be developed hydroelectrically at the end of ten years.

A start has been made on the electrification of the Japanese Government Railways, the first section to be electrified being that from Tokyo to Kobe, a distance of 374 miles. Based on operating experience in the United States, S. T. Dodd has estimated that to electrify all the main lines of Japan, of which there are about 7,000 route miles and 10,000 track miles will require about 135,000 kw. operating 24 hours per day, or allowing for a daily load-factor of 50 per cent, about 270,000 kw. of power plant capacity will be required. This electrification will be completed within ten years and the power required should be

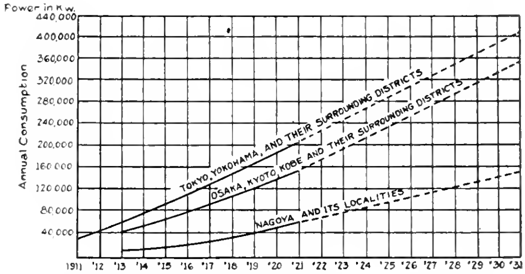

Fig. 3. Power Demand Curve for the Three Largest Divisions in Japan

added to the figure of 2,050,000 kw. required at the end of ten years for industrial load, and would bring the grand total of power demand to about 2,300,000 kw., or a three-fold increase over the total power now available.

It is interesting to compare these figures with similar figures for the United States. It is estimated that here there was in 1917 about 20,000,000 kw. of installed generating capacity. There was available for development about 45,000,000 kw. of water power, of which about 20 per cent or 9,000,000 kw. had been developed. There are about 265,000 route miles of steam railway or about 400,000 track miles, and to electrify this railroad would require about 5,500,000 kw. on a 24-hour basis or about 11,000,000 kw. assuming a 50 per cent load-factor.

Construction Work

The construction of the power plants and transmission lines follows closely that of American practice. The buildings themselves are often ornate and an architectural addition to the surroundings. The masonry work in connection with the dams, canals, etc., is of a very high class and installed in a permanent manner.

Excavation work as a rule is done by primitive hand methods. Dirt and stones are removed in rope baskets suspended from poles, each carried by two men. Hods carried on the back and wheelbarrows are often used. Men and women take part in this work and in some cases Koreans are used extensively. A few of the companies now use steam shovels and light gauge construction railroads and these labor saving methods will no doubt come more into use as labor conditions become worse. The Japanese laborer is hard working and patient but likes to do things in his own way. Coming from a line of individualists, workers in metal, wood, porcelain, etc., he has not yet learned to work in groups or to take orders from a foreman. He is also very sensitive to reprimand. The result is that work proceeds with surprising slowness and with an unnecessarily large number of men, according to our standards. In spite of this some very reasonable costs are reported for some of the developments. For example, the Daido Company report approximate costs based on about 167,000 kw. of generating capacity in operation or under construction as follows:

Fig. 4. View of the Shizumo Power Plant of the Daido Electric Power Company on the Kiso River

Fig. 5. Method of Excavating by Means of Rope Baskets

Fig. 6. Modern Method of Excavating by Means of Steam Shovels; Shinetsu Electric Power Company

Generating stations.	$170 per kw.
Substations.	38 per kw.
Transmission lines.	64 per kw.

That is, a total of 167,000 kw. in generating capacity, 264,000 kw. in substation capacity, and 350 miles of double-circuit 77- and 154-kv.

transmission line were built for approximately $270 per kw. of generating capacity. Putting it another way for the transmission line, 350 miles of double-circuit line were built at an average cost of $31,000 per mile. These figures compare favorably with costs obtained for similar work in the United States.

The inefficiency of the Japanese labor is offset somewhat by its cheapness. Rights-of-way we would also expect to be more reasonable than in the United States. Machinery costs are somewhat greater. Taken altogether, these factors tend to make the cost in the two countries about equal.

Operation and Government Regulation

The systems are manned by native operators who seem to be quite efficient and capable. Much the same methods are used as in the United States. The native costume is discarded by the operators in favor of foreign clothes, which are more suitable for working around machinery.

There is a rapid trend toward the interconnection and amalgamation of power systems serving the same territory, and the various problems arising from such interconnection are being solved in a very business-like manner.

In Japan all the water-power rights belong to the Government, regardless of whether the banks of the river are owned by the Government. Licenses for water-power development are given by the Governors of the Prefectures (corresponding to our State Governors) with the approval of both the Ministers of Communications and Home Affairs.

The administration and regulation of electrical developments is carried out by the Ministry of Communications in accordance with the Electric Enterprises Law, as follows:

(a) The Power Company applies for a license to the Ministry of Communications, accompanying its application with documents describing the object, the supply area, the general plan of the enterprise, etc.

(b) After obtaining the license the promoter submits plans of the technical construction with a precise description of all the structures pertaining to the development, such as dams, buildings, transmission lines, etc., to the Ministry of Communications. These plans must be approved by the Minister before proceeding with the work.

(c) On completion of the electrical installation, the equipment and lines are inspected and sometimes tested by the Government engineers before operation may be commenced. During operation also the installation is often inspected by the Government engineers.

(d) Regulations for electrical installations are issued by the Ministry of Communications. Those for overhead lines, for example, cover construction, clearance from ground, sag, distance from adjacent buildings, highways, railways, tramways, other overhead power lines, and communication circuits, etc. Others in similar detail cover the construction of dams, buildings, installation of spare equipment, etc.

After installation the insulation strength of overhead power lines is subjected to the following test:

Operating Voltage	Test Voltage Between Line and Ground for Ten Minutes
Below 50,000 volts	1.5 times the maximum operating voltage.
Above 50,000 volts	Max. operating voltage plus 25,000 volts.

For lead-covered cables the foregoing tests are made between each core of the cable and between each core and ground.

Where the neutral point of Y-connected generators or transformers is grounded through a resistance, the test voltages may be reduced as follows:

Operating Voltage	Test Voltage Between Line and Ground
Below 50,000 volts	1.25 times the maximum operating voltage
Above 50,000 volts	Maximum operating voltage plus 13,000 volts

The telephone and telegraph systems of the country are owned by the Government and controlled by the Department of Communications. The proximity of power lines and communication circuits has influenced the whole course of operation of the power systems in Japan. The principal point of concern seems to be not so much the interference with speech as the building up of a voltage on the communication circuit which may be dangerous to men working on these circuits. On this account, although there is no absolute ruling on the subject, it is generally considered that the short-circuit current on a system shall be limited to such a value as not to induce on a neighboring communication circuit a voltage in excess of 300; and as a practical interpretation of this ruling, power companies have been in the habit of inserting sufficient resistance in the grounded neutral to limit the short-circuit current to about 1.5 times the rating of one bank of transformers in the station. It is obvious upon consideration that 1.5 times the rating of a transformer bank will give greatly different values of current depending on the size of the transformer bank, and also that a certain current in one case may induce more voltage on communication circuits than a similar amount of current in another case, depending on the proximity of the communication circuit and the length of the parallel. In some cases, therefore, 100 amp. in the ground would have as much effect as 150 amp. in another case. For this reason it seems that some other rule than the present one should be established so that those power companies which are more or less immune from interference should be allowed to increase their ground current, as it is apparent that as much ground current as possible should be allowed to flow in order to facilitate positive and rapid relaying.

Grounding the neutral is done with a twofold purpose, namely, to reduce voltage stress and to produce more positive conditions for relay operation than possible on an isolated neutral system. If too high a resistance is used in the neutral, neither of these objects will be accomplished, and probably also telephone interference will not be eliminated. When there is an arc over an insulator, a charging current passes from the two ungrounded conductors to ground and back through the arc, the current in the ungrounded conductors being increased to about 130 per cent of the normal charging current and the current in the grounded conductor to about 200 per cent of the normal charging current. These currents lead their respective voltages. Now sufficient current must pass through the grounded neutral and the arc to counterbalance the leading current and make it predominately lagging, in order to eliminate the danger of arcing grounds and to permit the relays to operate. If sufficient current does not flow to accomplish this, then the circuit will not be cleared and the arc may become of the nature of an arcing or oscillating ground, with consequent liability of damage to insulation and interference with communication circuits. Thus if the neutral resistance allows only 50 amp. to flow and the charging current in case of a line ground is 200 amp., then the system is obviously in the class of an isolated neutral system.

It would seem that less trouble would be caused if sufficient current were permitted to pass through the neutral to permit positive and rapid relaying, and this is borne out by the operating experience of many power companies. A number of years' experience with isolated neutral proved conclusively that the extent and disastrous results of transmission line trouble was very largely due to arcing grounds on these systems. There is considerable evidence to show that the chief cause of permanent damage is due to the heat of the arc breaking the porcelain discs, but that a fair amount of time, say several seconds, is required for the damage to occur. It is not uncommon to have an arc occur over a string of insulators due to lightning or other cause, and when tripped off quickly, say in less than one second, to cause no physical damage whatever. The line trips out, is put back into service immediately, and operation is resumed. This of course is not possible with an isolated neutral system, as a secondary breakdown must occur to cause a short circuit; and in the meantime the original arc has been maintained a considerable length of time, and the system subjected to overvoltage strain.

On systems where the neutral is grounded without resistance, relaying is a comparatively simple matter and relays have been designed to take care of practically all known cases and combinations of lines. Such relaying has proved positive and reliable.

When the system is grounded through high resistance the situation becomes very difficult and none of the usual relays or relay schemes will operate. This will be readily appreciated from a study of Figs. 7 to 14.

Fig. 7 illustrates a system consisting of a generating station and a substation connected by two transmission lines. The high-tension neutral of the generating station transformers is grounded without resistance. The normal load current of each of the lines is assumed to be 300 amp. Now with a ground on one conductor at the substation end 2200 amp. flows into the ground. It is calculated from the constants of the assumed system that the generating station gives 400 amp. and that the remaining 1800 amp. is contributed by generators and other synchronous apparatus at the substation end. The current distributes as shown in Fig. 7a. It is evident that at the substation end, overload, reverse-power, balanced-reverse-power, or balanced-current relays would operate to clear the circuit in trouble and that afterwards the generating station end could be cleared by similar relays.

Likewise for a ground at the generating station end, 3200 amp. flows into the ground, of which 2000 amp. comes from the generator end and 1200 amp. from the substation end, as shown in Fig. 7b. As in the previous case the line in trouble could be cleared by the proper use of overload, reverse-power, balanced-reverse-power, or balanced-current

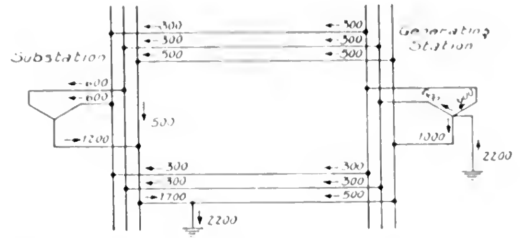

Fig. 7a. Two-circuit Transmission System with Neutral at Generating Station Grounded without Resistance. Conductor of one circuit grounded at substation end. Ground current 2200 amp. Current unbalance between the two circuits 1700-500 = 1200 amp.

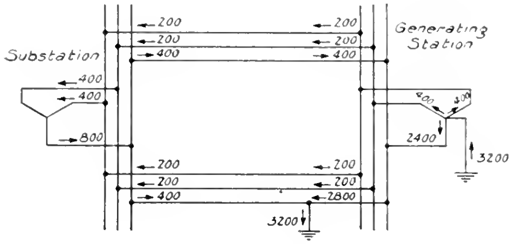

Fig. 7b. Same System and Conditions as in Fig. 7a Except that Conductor is Grounded at Generating Station End. Ground Current 3200 Amp., and Current Unbalance 2800-400 = 2400 Amp.

relays. The initial overload in these cases is from six to nine times and the unbalance between the lines from four to six times the normal load of one line.

In Fig. 8 is shown the condition with a line ground at the substation end and with sufficient resistance in the neutral ground to limit the short-circuit current to 150 amp. Fig. 8a shows the normal load current, Fig. 8b the distribution of short-circuit current, and Fig. 8c the distribution of line charging current. This latter current was also present (somewhat reduced) in the case of Fig. 7, but in that case it could be neglected as it did not form an appreciable part of the total current.

Now it will be seen from Fig. 8 that neither the short-circuit current nor the charging current nor their combination is sufficient to operate the ordinary overload, reverse-power, balanced-reverse-power, or balanced-current relays. In order to operate such relays, the overload or unbalance should in no event be less than 600 amp., that is, two times the load current of one line.

Fig. 9 shows the current distribution for a line ground at the generating station end. The conclusions from this case are the same as from that of Fig. 8, namely, that there is insufficient current or unbalance of current to operate the ordinary relays.

In Fig. 10 the condition of Fig. 9 is reproduced with the object of showing in detail how the currents pass through balanced-current relays. In this relay the two outside coils tend to hold down the moving mechanism. When the difference between the currents becomes sufficiently great, the middle coil will overcome the weaker of the two outside coils and cause the contact mechanism to be operated on the side to trip the breaker carrying the heavier current. The vector diagram at the left shows how these currents combine in the three coils. For example, in one outside coil 20 amp. short-circuit current combines with 40 amp. charging current to give about 45 amp. total; in the other outside coil 130 amp. short-circuit current and 270 amp. charging current combine to give about 284 amp. total; in the middle coil 150 amp. short-circuit current and 230 amp. charging current combine to give about 275 amp. total.

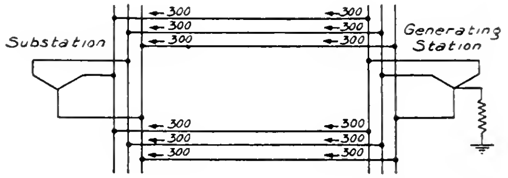

Fig. 8a. Two-circuit Transmission System with Neutral at Generating Station Grounded Through Resistance. Load current shown

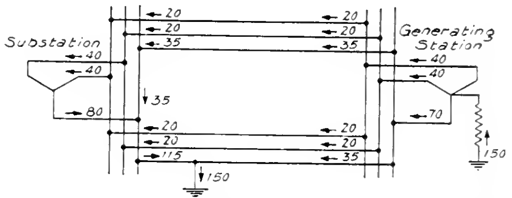

Fig. 8b. Same System as in Fig. 8a but with Conductor of One Circuit Grounded at Substation End. Short-circuit components of current shown, of which the unbalanced current is 115-35 = 80 amp.

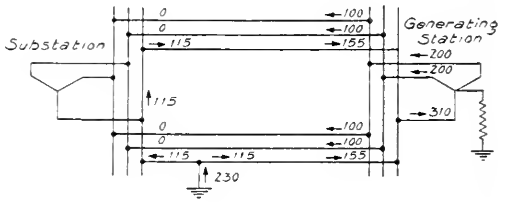

Fig. 8c. Same System as in Fig. 8b except that Charging Components of Current are Shown. No unbalance in these currents

If one line tripped at the substation end the full 600 amp. load current would presumably be thrown on the other line temporarily. In this case there would be 600 amp. through one outside and the middle coil of the relay, and zero amp. through the other outside coil. In order to prevent tripping the switch of the good line at the generating station end, it would be necessary to have the relay set for a difference greater than 600 amp. It is therefore necessary with this relay, and other similar relays, to have it set so it will not operate on a current less than two times the load current, which renders it useless for ordinary line-to-ground short circuits with the current limited by high resistance.

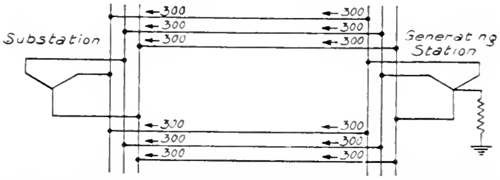

Fig. 9a. Two-circuit System with Neutral at Generating Station Grounded Through Resistance. Load current shown

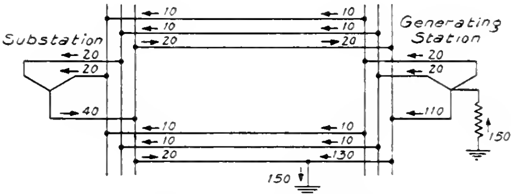

Fig. 9b. Same System as in Fig. 9a but with Conductor of One Circuit Grounded at Generating Station End. Short-circuit components of current shown, of which the unbalanced current is 130-20 = 110 amp.

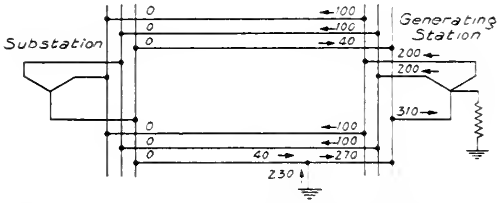

Fig. 9c. Same System as in Fig. 9b Except that Charging Components of Current are Shown, in Which the Unbalance is 270-40 = 230 amp.

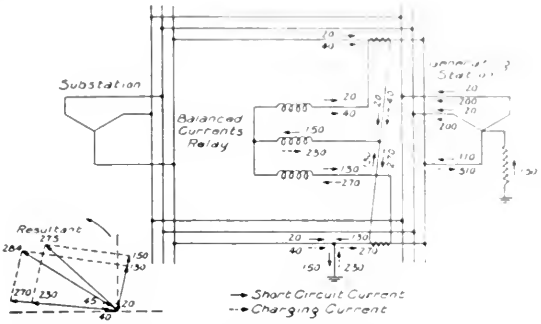

Fig. 10. Application of Balanced Relays to the System Under the Conditions Given in Figs. 9b and 9c, Showing the Effect of Line Ground on the Currents Through the Relay of One Phase Only

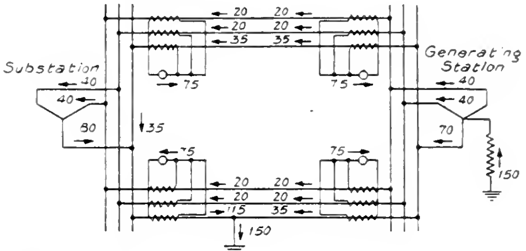

Fig. 11a. Application of Ground Relays to the System Under the Conditions Given in Fig. 8b, Showing the Division of Short-circuited Current Through the Relays

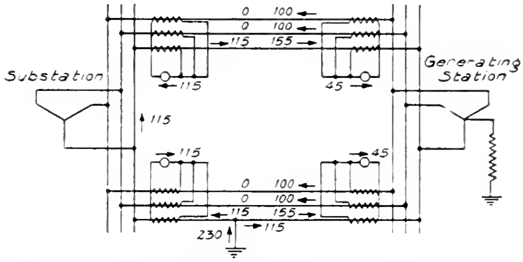

Fig. 11b. Application of Ground Relays to the System Under the Conditions Given in Fig. 8c, Showing the Division of the Charging Current Through the Relays

A so-called ground relay operating on the unbalanced current in the three conductors of one line is sometimes used. This may be set for comparatively small currents. Fig. 11 shows the use of this relay for the case of a line ground at the substation end. It will be noted that there is no difference in the currents in the relays of the good and bad lines, and therefore there would be no discrimination. Both lines would go out if the relays were set low enough. The case of a line ground at the generating station end is illustrated in Fig. 12. Here it is probable that the faulty line would go out due to short-circuit current and the good line due to charging current. For line grounds between the generating and substation ends there would be equally objectionable combinations of current. It is evident that this relay should not be used on such a system.

A special balanced relay has been developed and promises to solve to a large extent the relay problem on such systems. This relay has a current element and a reverse power or directional element. The current element is actuated by the difference of current in the two lines, and the potential coil of the directional element is actuated by a potential in phase with the ground current, by taking a portion of the voltage drop across the grounding resistor as shown in Fig. 13. The current flows through the relay in one direction for a ground on line 2, Fig. 13a, and in the other direction for a ground on line 1, Fig. 13b, while the potential is in the same direction in both cases. In this sketch the full lines with arrows represent short-circuit currents and the dotted lines with arrows represent charging currents. The vector diagram at the left shows the direction of the short-circuit and charging currents and their resultant, and the direction of the voltage drop E_r, and its projection E_p on the resultant current. In the case of Fig. 13a the voltage E_p and resultant current are in phase, and in the case of Fig. 13b they are 180 deg. out of phase. The relay has two sets of contacts, one set of which will be closed in the case illustrated in Fig. 13a and the other set in the case illustrated in Fig. 13b, thus tripping the switch of the line in trouble. The current element of the relay provides a minimum operating point and time delay. Under one-line operation the relay would tend to trip the oil circuit breaker on the line which produced a flow of power outward from the bus. Normal current with one line in operation would not cause the relay to act as there would be no potential, this potential existing only when current flows through the ground resistance. Inverse time limit overload relays are provided to take care of line-to-line short circuits or bus short circuits, there being in this case no discrimination between the two lines. Such short circuits, however, would probably be so rare as to justify the risk of losing both lines. Other means could be provided to take care of line-to-line short circuits in a discriminating manner such as the use of balanced-current relays in addition to the special balanced relay and in some cases this may be desirable.

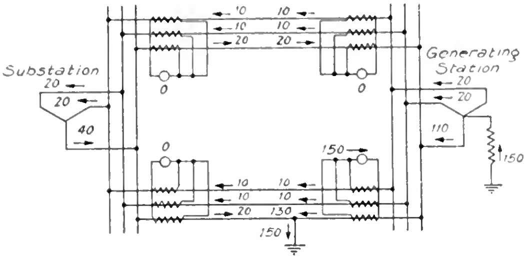

Fig. 12a. Application of Ground Relays to the System Under the Conditions Given in Fig. 9b, Showing the Division of Short-circuit Current Through the Relays

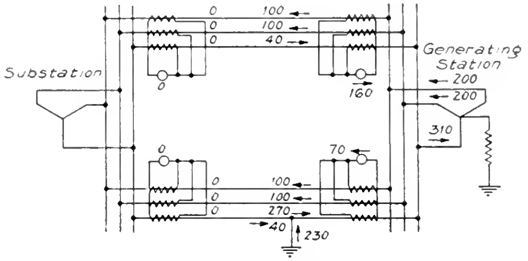

Fig. 12b. Application of Ground Relays to the System Under the Conditions Given in Fig. 9c, Showing the Division of the Charging Current Through the Relays

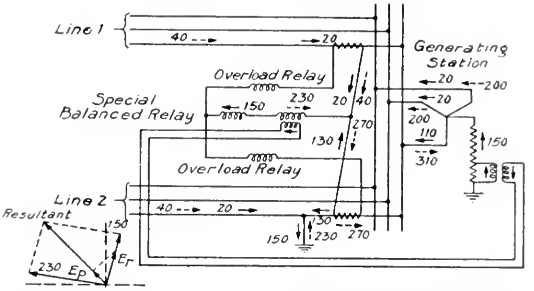

Fig. 13a. Application of Special Balanced Relay to the System Under the Conditions Given in Figs. 9b and 9c, Showing the Effect of a Ground, on a Conductor of Line 2, upon the Currents Through the Relay of One Phase Only. Potential for relay is obtained from a portion of the neutral resistance

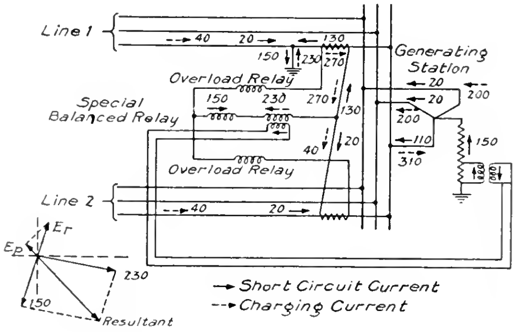

Fig. 13b. Same System and Conditions as in Fig. 13a Except the Ground is on a Conductor of Line 1

At the substation end of the line or at switching stations where the neutral is not ordinarily grounded, potential for the special balanced relay is more difficult to obtain.

This may be done, however, as illustrated in Fig. 14 by the use of three potential transformers connected Y with grounded neutral on the high-tension side and open delta on the low-tension side. The delta is closed through the potential coil of the relay. In the case of a line ground a voltage will be produced across the relay coil in phase with the voltage produced at the grounded end of the line by the current passing through the resistor. Another method, for the substation end, is to place resistance in the neutral at this end of the line also and tap off this resistance with potential transformers, the same as at the generating station end.

Even with the type of relay just described, the more ground current allowed to flow the more positively will the relay operate and the more leeway will there be in setting the current elements, the overload relays, etc. So from all standpoints it is desirable to reduce the neutral resistance as much as possible, thereby rendering the whole relay problem much simpler and more flexible.

An effort has been made by the Department of Communications to protect communication circuits from power lines by the introduction of a balancing transformer in the communication circuit as shown in Fig. 15. It is claimed that this has given good results as far as cutting down the inductive interference is concerned, but that such a transformer impairs the efficiency of the telephone transmission. Efforts have also been made by the Electrotechnical Laboratory of the Department of Communications to develop sensitive low-voltage arresters to take care of over-voltage on the telephone circuits.

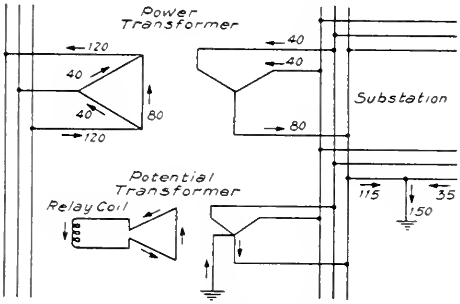

Fig. 14. Method of Obtaining Potential for the Relay Used in Figs. 13a and 13b at the Substation End, where the Neutral Resistance is not Available

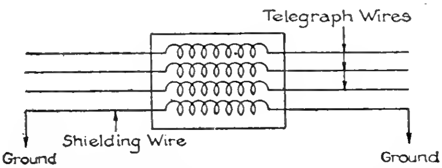

Fig. 15. Proposed Balancing Coil for Eliminating Interference on Communication Circuits

In the United States neither the telephone nor the power systems are operated by the Government. Both of them exist side by side and stand on their own feet Here the telephone communication is probably the best and most advanced of any country in the world. The telephone company has a large staff of very able and efficient technicians, and the telephone interests are well protected by these representatives. The result is that there is very little trouble from interference, and when such trouble does arise it is remedied by joint action between the telephone and power company engineers.

Fig. 16. Power Plant No. 1 of the Inawashiro Hydroelectric Company

From the writer's observation of the Japanese telephone system it seems to be rather out of date and inefficient. Perhaps the remedy for the interference complained of by the Department of Communications is not in hampering the operation of the power systems but in modernizing and placing in first-class condition the communication circuits.

Conclusion

In 70 years time, Japan has made a marvelous transformation from an isolated feudal state to one of the most powerful and influential countries in the world. Accompanying this transformation has been a change in occupation from agriculture and home industries to the large mechanically operated industries of the modern western world. Mechanically speaking, Japan is therefore only about 70 years old and it is natural that the mechanical sense has not yet been fully developed among the people. Considering the great strides that have been made and the thoroughness with which modern methods are adopted and put into practice, we may expect within the next few years a wonderful development along industrial and mechanical lines

Low-power Radio Telephone and Telegraph Transmitter

By I. F. Byrnes

Radio Engineering Department, General Electric Company

The articles we have so far published on radio telephone and telegraph transmitters have described high-power commercial outfits. The low-power outfit described in the following article is of compact size, substantial construction and is conveniently operated. It ably fills the widespread need for a telephone and telegraph transmitter to cover moderate distances.—Editor.

A previous article* has indicated the equipment available for commercial radio telephony and telegraphy. The transmitter described in the present article is designed for service on yachts or small vessels where only relatively short distance transmission is required, but this equipment also has possibilities as an amateur transmitter.

Its normal rating as a continuous-wave telegraph transmitter is 20 watts input into the antenna. This requires the use of four 5-watt radiotrons (UV 202) operating as oscillators. For telephony two of these tubes function as oscillators and the other two as modulators, thus giving an antenna input of 10 watts when not modulating. When speaking into the transmitter the modulated antenna input rises to instantaneous peak values of 30 to 40 watts. Power for the radio transmitter proper may be obtained either from a kenotron rectifier that uses four 20-watt kenotrons (UV 216) or from a motor-generator. The rectifier operates from a 110-volt 60-cycle lighting circuit.

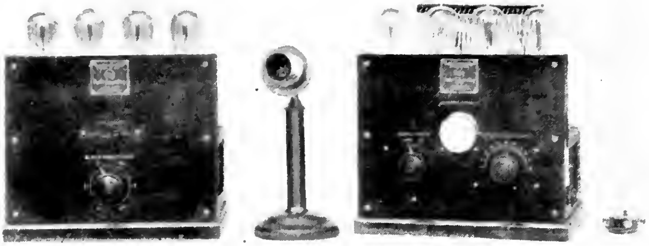

Fig. 1. Front View of Rectifier and Radio Transmitter

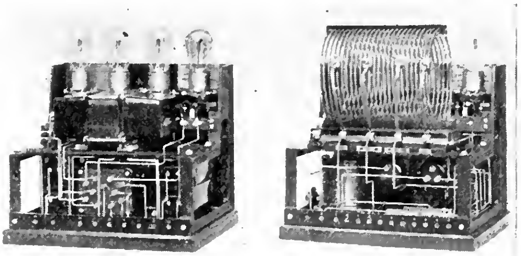

Fig. 2. Rear View of Rectifier and Radio Transmitter

Front and rear views of a complete equipment are shown in Figs. 1 and 2. The unit on the left is the kenotron rectifier† while the unit on the right is the radio transmitter.‡ A standard desk-type microphone and a telegraph key are also part of the equipment. The small size of the kenotron and transmitter units is apparent when they are compared with the desk microphone. In the design of the entire equipment particular attention has been directed to make it substantial and safe to operate. Rigid busbar

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*"Commercial Radio Telephone and Telegraph Transmitting Equipment," by W. R. G. Baker and B. R. Cummings, General Electric Review, October, 1922, p. 603, and November, p. 666.

†Model ET 3620.

‡Model ET 3619.

wiring connects the component parts in each unit. All controls on the front of the panel may be operated without danger to the operator or equipment. Interconnections are made from the rear with the result that the units present a neat appearance when installed.

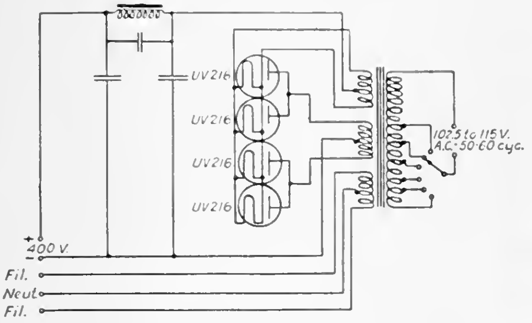

Fig. 3. Schematic Diagram of Kenotron Rectifier

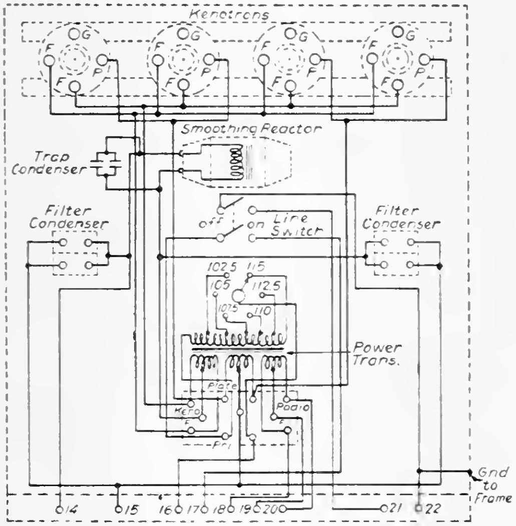

Fig. 4. Complete Diagram of Kenotron Rectifier

A vacuum-tube radio transmitter requires a low-voltage source of direct-current or alternating-current for the tube filaments, while the plate circuit must be operated on direct-current at a potential of several hundred volts. Both of these conditions are fulfilled by the kenotron unit. The schematic circuit arrangement of the rectifier is shown in Fig. 3 and the actual connection diagram in Fig. 4. Referring to the schematic diagram it will be seen that the transformer is wound with three secondaries. Two of these deliver power to the kenotron and radiotron filaments while the center winding connects to the plates of the kenotrons. The taps on the primary of the transformer permit the filament voltage to be maintained at 7.5 volts over a range of line voltage from 102.5 to 115. The plate winding delivers a potential of 1100 volts between outer leads or 550 volts between the mid-tap and either leg.

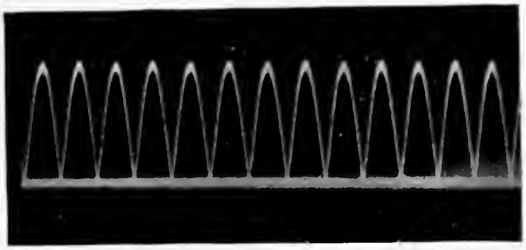

Fig. 5. Oscillogram of Rectifier Output Wave without Filter

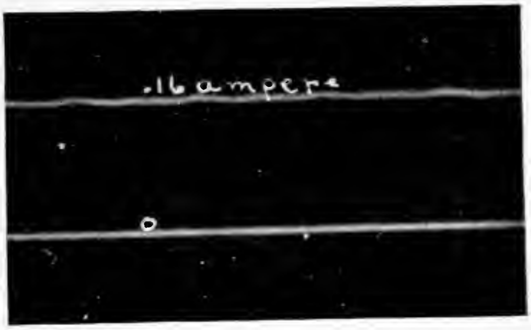

Fig. 6. Oscillogram of Rectifier Output Wave with Filter

The arrangement of tubes in Fig. 3 constitutes a single-phase full-wave rectifier, two of the kenotrons operating in parallel from each leg of the 1100-volt winding. Due to the unilateral conductivity of the tubes, current passes only when the plate or anode is positive. Thus the plate winding delivers current first through one leg and then through the other, making the mid-tap on the kenotron filament winding the positive side and the mid-tap on the plate winding the negative side of the resultant direct-current output. If no filter or smoothing circuit were used the output current would appear as shown in the oscillogram in Fig. 5. The frequency of the pulsations is twice the frequency of the power supply because both halves of the cycle are rectified.

For telephony, a plate supply that pulsates as in Fig. 5 is unsuitable because such variations will cause a ripple whose amplitude approximates the signal produced by the voice and this ripple will be heard at the receiving station. Therefore a filter circuit is used to smooth out the rectified pulsations. This filter consists of a combination mesh and tuned circuit and is made up of condensers and a reactor. The reactor and condenser in parallel (Fig. 3) are tuned to the ripple frequency and, being in series with the direct-current line, offer a very high impedance to the alternating-current component in the rectified wave. The condensers, on the other hand, that are connected across the line serve to store energy when the rectifier output is rising and then deliver it to the load as the kenotron voltage falls. It is evident that the condensers cannot discharge back into the tubes due to the valve action of the latter. The final shape of the output current of the rectifier is shown in Fig. 6. The ripple present is generally of the order of three per cent or less and does not introduce any appreciable interference for either telephony or telegraphy.

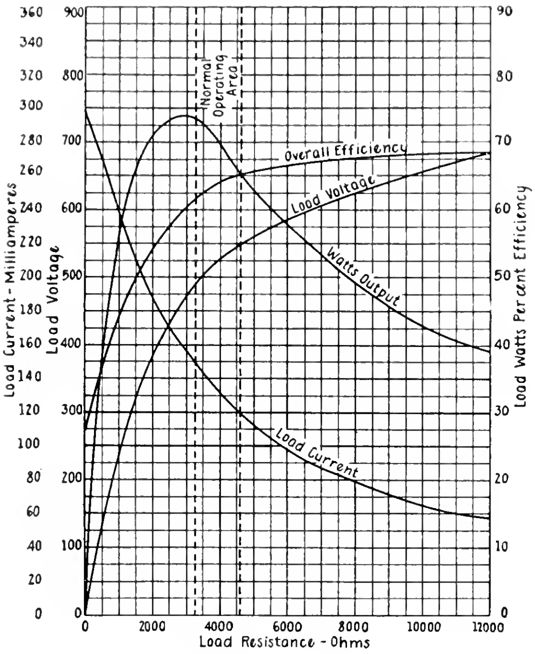

Fig. 7. Rectifier Characteristic Curves

The characteristics of the kenotron rectifier are plotted in Fig. 7. These characteristics were obtained by placing different resistance loads across the high-voltage output of the rectifier. The overall efficiency was computed as the ratio of kenotron output watts plus radiotron filament watts over the total primary input to the transformer. The actual overall rectification efficiency of the kenotrons themselves is not high in low-power equipments due to the fact that the energy expended in heating the rectifier filaments often equals or exceeds the plate output. It will be seen that the load voltage falls very rapidly as the load resistance is decreased.

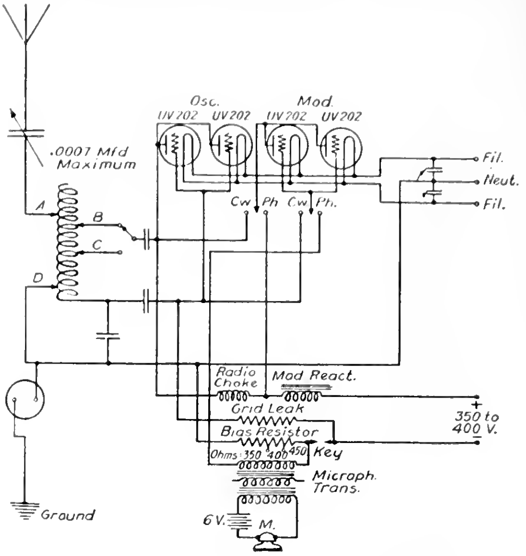

Fig. 8. Schematic Diagram of Radio Transmitter

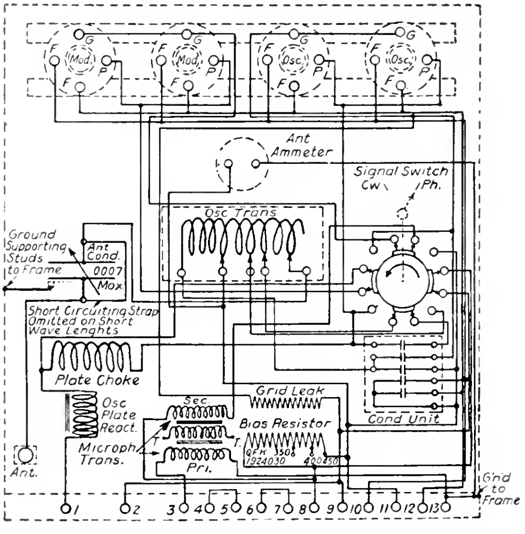

Fig. 9. Complete Diagram of Radio Transmitter

This is caused mainly by space charge drop in the kenotrons themselves. The regulation improves as the ratio of load resistance to plate resistance increases, except at zero load when the output voltage equals the peak value of the kenotron plate voltage. This latter condition occurs because the smoothing condensers, at zero load, remain charged at the maximum voltage that is impressed upon them. Referring to Fig. 7, the area between the dotted lines represents the normal operating conditions. In other words, the radio transmitter acts as a resistance load on the kenotron plate output with an average value of about 4000 ohms.

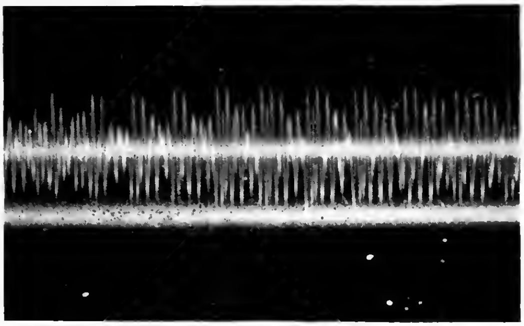

Fig. 10. Oscillogram showing Envelope of Antenna Current with Telephone Modulation

The fundamental circuit of the radio transmitter appears in Fig. 8, and a complete circuit diagram of the unit is shown in Fig. 9. In considering the operation of the transmitter, reference will be made to the fundamental diagram. The radio transmitter has two main functions to perform. For telegraphy the radiotrons (UV 202) must convert their direct-current plate supply into alternating current at radio frequency. The signal switch is arranged to permit all four tubes to operate as oscillators for continuous-wave telegraphy. In order to telephone, two of the tubes are connected as oscillators while the other two act as modulators, or speech control tubes for the oscillators. Before considering the modulating circuits the operation of the transmitter oscillating circuits will be described.

It is a well-known fact that a three-electrode vacuum tube will oscillate or generate alternating-current power if the grid circuit is coupled, in proper phase, to the output circuit. This coupling is obtained in the transmitter by means of an oscillation transformer. The oscillation transformer consists of a copper strip helical coil with a total inductance of about 65 microhenries. When the line switch on the kenotron unit is closed and the telegraph key is depressed, direct current flows from the rectifier through the modulating reactor and the radio choke to the plates of the oscillators. The circuit is closed through the oscillator tubes to the negative side of the rectifier circuit through the nid-tap of the filament transformer winding and the bias resistor. The first inrush of current through the oscillator tubes sets up a momentary impulse in the circuit which includes the turns on the oscillation transformer *B* (or *C*) and *D*. This in turn induces feeble oscillations in the antenna circuit of a frequency determined by the inductance and capacitance of the antenna system and the inductance between the turns *A* and *D*. The grid-filament circuit of the oscillators, being connected to the lower end of the oscillation transformer, has induced in it oscillations of the same frequency as those in the antenna. This causes the current in the plate circuit to follow the grid potential variations until the oscillations in the system reach a maximum amplitude determined by the tube and circuit constants. The condenser, in series with the alternating-current plate circuit, serves to prevent the direct-current circuit from passing to ground through the oscillation transformer and at the same time acts as a low-impedance path for the radio frequency. The alternating-current potential impressed on the grids of the tubes is rectified during the positive half of the cycle and sends current through the grid leak. The IR drop across the grid leak determines the negative bias voltage on the oscillators.

A 5-watt radiotron (UV 202) operates most efficiently as an oscillator under average conditions when the alternating-current plate potential is 190 volts and the alternating-current grid potential is 120 volts. These voltages are determined mainly by the reactive drop across the plate and grid sections of the oscillation transformer. Since more antenna current is obtained on continuous-wave than on telephone operation, the drop per turn is greater. Provision is made therefore to change the plate tap by means of the signal switch when shifting from continuous-wave to telephone operation or vice versa. The grid turns do not carry antenna current and are less critical to variations in this current. For this reason the grid tap is not changed by the signal switch. The condenser shunted around the grid turns serves to tune the grid circuit and enables the requisite grid voltage to be established without the use of excessive inductance on the oscillation transformer. A radio choke coil is connected in the positive side of the plate circuit in order to prevent the plate alternating-current component from passing back into the rectifier. The by-pass condensers, connected from the neutral to each leg of the filament circuit, are used to furnish a low-impedance path to the grid and plate alternating-current components.

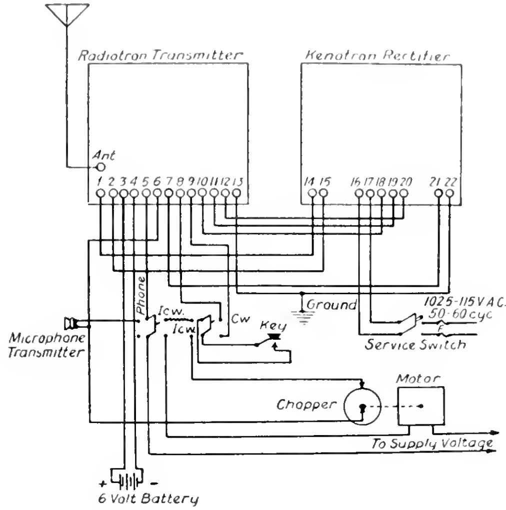

Fig. 11. External Connections of Complete Equipment

The method used in keying the transformers for continuous-wave telegraphy is of interest. Heretofore, it has been customary to open the grid leak with the key or to open the plate circuit directly in order to stop oscillations. The first method is liable to give incomplete control as oscillations may not cease entirely when the grid leak is opened. The second arrangement is productive of injurious sparking at the key contacts even in low-power transmitters. Referring to Fig. 8, it will be seen that when the key is opened the grid leak connects to the negative side of the plate circuit. This side of the plate circuit is also disconnected from the radiotron filaments. Under these conditions no oscillations can take place. When the set is keyed the grid charges up negatively each time the key opens, and since this reduces the plate current to nearly zero no sparking occurs, notwithstanding the fact that the plate circuit is opened by the same contacts.

Telephone control is accomplished in this transmitter by means of the familiar plate modulation system. If a curve is plotted between antenna current and oscillator plate potential, approximately a linear characteristic will be obtained. Hence if the speech were made to vary the plate potential, the antenna current would be molded or modulated in proportion to the amplitude and frequency of the voice vibrations. The microphone transmitter is connected in series with the primary of a microphone transformer and a 6-volt battery. Current variations in the primary set up a potential in the secondary which is impressed between the grid and filament of the modulator tubes. The bias resistor is used in order to maintain a fixed negative potential on the modulator grids so that these tubes will operate on the straight portion of their characteristic curve. The IR drop across this resistor is determined by the direct-current plate component. As the modulator grid potential is varied, the plate current varies which must pass through the modulating reactor. An audio-frequency voltage is thus built up across the reactor and aids or opposes the normal plate potential. The resultant envelope of the antenna current is shown in the oscillogram in Fig. 10. This oscillogram indicates that the antenna current is varied from zero to about twice its non-modulated value, corresponding to practically 100 per cent modulation.

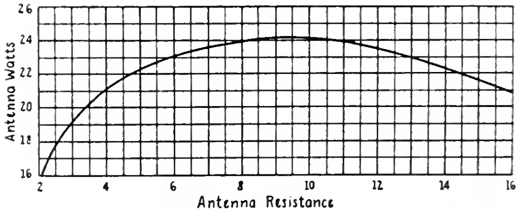

Fig. 12. Curve showing Effect of Antenna Resistance on Output

In addition to telephony and continuous-wave telegraphy, it is possible to obtain interrupted-continuous-wave telegraphy by the use of a motor-driven chopper. The chopper is used to interrupt a circuit at audio-frequencies and in practice is connected in place of the microphone as in Fig. 11. Then, with the signal switch in the telephone position and the key in series with the chopper, it is possible to modulate the transmitter output each time the key is depressed. Motor-driven choppers are generally used to interrupt the circuit about 1000 times a second.

The effect of antenna resistance on the output of the transmitter is plotted in Fig. 12. This curve was obtained with four oscillators under continuous-wave conditions at 200 meters. Since the average antenna seldom has a resistance as low as 4 ohms at 200 meters, it is evident that the transmitter will deliver rated output over a considerable range of antenna resistance. When used with the average small antenna, the equipment will cover a wavelength range from 180 to 320 meters. On short waves, most of the tuning is accomplished with the variable series antenna condenser. When transmitting on the longer wavelengths, this condenser may be short circuited and the taps on the oscillation transformer adjusted to obtain the desired wavelength.

For installations where only direct-current power is available, a small motor-generator set is used to replace the kenotron rectifier. In this case the plate supply is obtained from the generator and the filaments are heated by a transformer whose primary is supplied from the slip rings on the motor windings. Under average conditions, using alternating-current supply, the total primary input to the kenotron rectifier is about 300 watts.

Summary of High Tension Underground Transmission Practice and Development

By G. B. Shanklin

Lighting Engineering Department, General Electric Company

Underground cable practice in America is receiving more attention that it merits now than it has in the past. The author after discussing the advances made in the art and giving certain data concerning the three- and single-conductor cables installed in America compares the development with that in Europe. He then compares the relative merits of three-conductor and single-conductor cables and discusses joints, dielectric strength, internal ionization and heating of cables.—Editor.

Until recent years cable practice was looked upon by most engineers as a separate branch of electrical engineering obscured in a maze of "trade secrets." The geometrical cross section of cables offered an attractive problem to the theoretician and mathematical formulas dealing with electrostatic and magnetic properties were deduced years before the engineering problems had made much progress. There was at that time a wide gap between the theoretical and practical cable activities, but gradually this gap has been filled until today the whole field of cable engineering rests on a fairly solid foundation, with a majority of electrical engineers having some knowledge of its fundamental principles and varied details.

Cable Committees

The more general this knowledge becomes the greater the progress will be, for cable practice and development more than any other phase of the electrical arts is dependent upon co-operative effort.

Committee work in England and America has been a vital progressive factor, not only due to direct contributions in the field of research and development but, more important, to the co-ordination and shaping of independent developments. Co-ordination of accepted standards of practice has also made Committee work indispensable.

The chief contributing Committees in the United States have been the Transmission and Distribution Committee of the A.I.E.E., and the Underground Systems Committee of the N.E.L.A., whose "Specifications for Paper Insulated Cables" have accomplished a great deal. The annual reports covering their activities are accepted standards of reference. There is a joint Sub-Committee on Cable Research of these two organizations which is pursuing a very broad research program. The Insulation Committee of the National Research Council is now laying out a program covering the fundamental characteristics of gaseous, liquid and solid insulation. As soon as this work is actively under way it will prove of valuable assistance to cable work. There is also the Sectional Committee on Insulated Wires and Cables, of the American Engineering Standards Committee, which is at work on the collation and distribution of useful data and information.

Advancement

There has been a decided increase in standards of high voltage underground cable practice during the past few years. The manufacture and operation of cables is now more of an exact science, with the many varied factors better understood and under much better control. That there is still unlimited room for improvement does not detract from these accomplishments.

In reviewing this advancement, the one outstanding feature has been the inclusion of a dielectric loss clause in cable specifications. It has resulted in a closer study by both the manufacturer and operator, with a consequent reduction in dielectric loss and increase in quality of insulation on the one hand and a better understanding of loading and heating conditions on the other.

Previous to these specifications the quality of insulation was such that the dielectric power-factor at 100 deg. C. varied anywhere from 15 to 50 per cent. The A.I.E.E. Standardization Rules allow a maximum operating temperature of 85 deg. C.—E, where E represents line kilovolts. With such high dielectric losses as mentioned above, the critical temperature at which accumulative heating and failure occurred was too near the allowable operating temperature. The margin of safety was so narrow that frequently it was over stepped, particularly so with the higher voltage cables at points along the line called "hot spots" where, due to congestion of cables, sources of external heat, etc., the ability to dissipate heat from the ducts was inadequate.

The cable furnished today shows a power-factor of from 1.5 to 12 per cent at 100 deg. C. with the majority of cables running considerably lower than the 12 per cent maximum. This reduction has meant a corresponding increase in quality of insulating material, not only from a dielectric loss standpoint, but from all standpoints. The dielectric strength has been improved and the paper wrappings are more compact and more thoroughly filled than heretofore. Instead of the critical temperature at which accumulative heating starts being too near the allowable operating temperature of 85 deg. C.—E, it is now so far above that the question of revising this rule frequently comes up. It is claimed that the maximum operating temperature should now be based on the physical deterioration of the paper or the effects of expansion and contraction, depending upon which is found to be the limiting feature.

A good deal of work has already been done in an attempt to determine the temperature limit of paper cable insulation. The results were published in the A.I.E.E. Journal, February and March, 1921, and resulted in general disagreement. Some engineers felt that this work, together with accumulated experience, warranted an increase in temperature limit, while perhaps even a larger number were opposed to this increase. Since then the Cable Research Committee has started an additional series of tests and it is hoped that the question will eventually be settled.

Increase of Operating Voltage

The general trend of cable development is towards higher voltages. Cable lines representing very considerable increase in operating voltage are now actually in service both here and abroad with other lines under construction, while additional installations are being seriously considered. There can be no question regarding the economic need of these developments. The concentration of huge central station loads and the distances to which they must be transmitted practically demands higher voltages.

Three-conductor Cable: One of the large Central Station Companies in the Middle West has had several miles of 33-kv., three-conductor cable in operation during the past year. They are so pleased with the results that plans are now under way for 44-kv. operation. A smaller amount of 33-kv. cable has been in operation in Los Angeles since June, 1921, and a more extensive installation of similar cable is planned.

The above are the only important installations of three-conductor cable above 25-kv. rating in America. In Europe, however, such installations are becoming quite common. The first was of 30-kv. rating, installed in Berlin about 1912. Since then several installations of 33-kv. cable have been made in England and elsewhere. There is a recent 50-kv. three-conductor installation in Holland. It has not yet been placed in operation at full voltage and there remains some doubt whether a voltage of 50 kv. will eventually be used.

Rumors have emanated from England concerning a three-conductor "super-cable" rated at 66 kv. and these rumors have been strengthened by an advertisement of one of the responsible cable companies offering to quote on cable of this rating. A short length has been installed at a river crossing but at the present time this cable should be looked upon as purely experimental.

Single-conductor Cable: There has been parallel progress in the development of single-conductor cable. One of the first installations, a single-phase 60-kv. line with mid-point grounded, was made in Germany in 1911. After considerable trouble its use was discontinued in 1917. The next important installation was made at Barcelona by an Italian Company in 1914. It represented about nine miles of 50-kv. cable and its operation has been very successful. The St. Gotthard 60-kv. single-phase line in Switzerland (1920) was next, although in the meantime several short lines in the nature of ties and river crossings, rated from 40 kv. to 60 kv., were installed in Europe and America. The St Gotthard line has, according to reports, also given trouble and at least part of the cable is to be replaced by a more conservative design.

The most extensive single-conductor installation so far made has been the 60-kv., 3-phase, 50-cycle lines from the new Gennevilliers Station supplying the suburbs of Paris. These lines total 60 km in length and were put in operation a few months ago. It is understood that certain troubles of a remediable nature were encountered and the voltage reduced to 45 kv. It has since been gradually increased in steps to the original 60 kv. An article describing this installation appeared in the *Revue General de l'Electricite*, March 3, 1923.

There are two interesting installations of single-conductor cable now in progress here in America. An Eastern company is installing a 45-kv., 3-phase line several miles in length. Another large company in the Great Lakes section is installing four 66-kv., 3-phase lines from eight to fourteen miles in length.

In the Annual Report of the Transmission and Distribution Committee of the A.I.E.E. for 1922, there appeared a tabulated list of high voltage cable installations, together with data on insulation thickness, etc. This table is so comprehensive and valuable that we take the liberty of reproducing it in this article as Table I.

TABLE 1

DATA ON HIGH-VOLTAGE CABLES

From 1922 Report of Transmission and Distribution Committee of A.I.E.E.

Location	Date	Normal operating voltage	Size of Conductor cm.	Thickness of Insulation		Maximum dielectric between conductors kv. per cm.	Stress to sheath
				Conductor	Belt		
				Inches	Inches		
1 Chicago	1921	33,000	350,000	0.297	0.11	29.4	26.7
2 St. Paul	1900	25,000	66,400	0.281	0.125	32.8	27.2
3 Manchester	1921	33,000	382,000	0.25	0.25	32.3	22.8
4 Birmingham	1921	33,000	255,000	0.25	0.25	34.6	24.4
5 English Cable	1921	33,000	95,500	0.25	0.15	41.5	33.6
6 Normandy	1914	33,000	79,000	0.216	0.216	47.3	33.4
7 Paris	1921	60,000	295,000*	0.538	....	...	40.5
8 Erith (England)	1921	33,000	320,000	0.25	0.25	33.6	23.4
9 Rome	1913	30,000	39,500	0.473	†	47.7	
10 Florence	1916	40,000	148,000*	1.18	....	22.3	
11 Turin	1916	38,000	138,000*	0.67	....	28.7	
12 Turin	1917	38,000	99,000*	0.646	....	31.4	
13 Rome	1919	30,000	49.400	0.630	†	38.7	
14 Naples	1919	32,000	237,000	0.590	†	30.6	
15 Rome	1920	30,000	59.000	0.552	†	39.8	
16 Barcelona	1914	50,000	99.000*	0.552	....	45.1	
17 Clyde Valley	....	33,000	237,000	0.512	†	34.4	

Sources of information:

1, 3, 5, 7 Private sources.
2 Transactions, A.I.E.E., Vol. XVII, 1900.
4 London *Electrical Review*, April 22, 1921, Page 528.
6 M. Delon at N.E.L.A. Convention, 1921, discussion on Underground Systems Report.
8 *Electrical Times* (London), Sept. 29, 1921.
9 to 17 from Mr. Guido Semenza, Milan, Italy.
No. 1 has sector shaped conductors; all other are round.
Dielectric stresses calculated according to Davis & Simon (Journal A.I.E.E., January, 1921)

*Single-conductor cables. All others are three-conductor.

†Not given.

Experimental Cable Lines

An 80-kv. single-conductor cable line is being installed in Italy. No definite detailed information is available concerning this line but it is understood to be relatively short in length and, although it will transmit power, is more in the nature of an experiment. Certain unique features are understood to be incorporated in the cable design, including a liquid oil filler. It is probable that new departures from established cable practice will have to be followed to take care of contraction and expansion and to prevent migration and leakage of the oil. If these problems can be met in a practical way it will mean a big step forward in operating voltage. The use of a thin liquid filler would prevent voids which are produced in the present type of cable by handling and by contraction and expansion during operation. These voids necessarily limit the voltage stress.

One of the operating companies here in America has laid out a co-operative plan to install a 132-kv., 3-phase experimental line of single-conductor cable not over one mile in length and consisting of various types of cable. This experiment should prove very valuable.

Comparison of Cable Developments in Europe and America

In comparing the preceding lists of cable installations in Europe and America, one cannot help but notice that the trail is always blazed in Europe. Without detracting in the slightest from the credit due European engineers it might be stated that this does not mean that American practice is too conservative nor that we are backward in development. It is a perfectly normal situation largely due to the different conditions which surround cable practice in Europe and this country. The chief difference is the use of buried cable in Europe and cable drawn into ducts here. The concentration of load is so great and conditions change so rapidly that American operators are practically forced to sacrifice the advantages of buried cable in the interests of the more imperative demands of accessibility.

Buried cable lends itself exceptionally well to extra high voltage operation. It is not subjected to strain and severe bending during installation, there is plenty of room for jointing, it dissipates the heat better than cable in ducts, and cable diameter is not limited by duct size. European cable is less heavily loaded, due to the fact that load congestion is not nearly so great, and runs considerably cooler than American cable. All of which leads to assurance of a more compact cable with fewer and smaller voids. The above comparison also accounts for the somewhat thinner insulation and, consequently, higher voltage stressing followed in European practice.

Comparison of Three-conductor and Single-conductor Cable

A few years ago there was a good deal of uneasiness regarding tangential stressing in three-conductor cable. Sections near a fault were frequently found with the central triangle and adjoining paper wrappings badly charred. It was at first assumed that the strength in this section was too low and the stress too high in proportion to the rest of the cross section. Later developments would indicate, however, that three-conductor design is not so badly unbalanced and that the trouble was mainly due to poor grade material and heavy loading.

Paper cable insulation is inherently weaker in a lateral direction than in a direction perpendicular to the wrappings, due to the fact that the surfaces are smooth and do not lie in absolutely intimate contact. The barrier effect offered by the fibers is consequently less in a lateral direction. Based on this reasoning, lateral stressing is a weak point in three-conductor design but, now that high grade materials are available and loading conditions better appreciated, it is an open question whether it will be the limiting feature in future increase of operating voltage. As the voltage increases the difficulty of making three-conductor splices of reasonable size will increase rapidly. Even today it offers a serious problem, due to the complicated structure. Overall diameter of cable might also have some influence. Cables of 33-kv. and 44-kv. rating are already nearly as large as present practice is willing to accept, 66-kv. three-conductor cable would be of almost prohibitive size for duct operation.

This cable is favored in England because of the necessity of using steel armor on buried cable. Magnetic armor cannot be used on single-conductor cable due to high induced sheath losses.

By the time we reach such voltages as considered above the three-conductor cable must compete with the single-conductor type, with its absence of lateral stressing, compact construction, small diameter, simplicity of joints and end bells and lesser cost. Instead of having the full line voltage under a common sheath there is only the voltage to ground. By taking simple precautions, short circuits between phases can be eliminated and the hazard to apparatus thereby reduced. At these voltages the induced sheath losses will be small, provided magnetic armor is not used, something in the order of 15 to 30 per cent of the copper loss at 60 cycles. There is not a corresponding increase in temperature rise and reduction in carrying capacity, however, as the sheath loss does not have to be conducted through the insulation. The reduction in carrying capacity would be not more than 4 per cent.

Cable Joints

The problems connected with cable jointing have not received the same helpful co-operative attention that other and no more important problems have. Cable joints are largely hand made. This involves a certain amount of personal element and the problems are usually accepted as individual to each operating company.

When the ratio between the number of joint failures and total length of joints in any given line is compared with the corresponding ratio for the cable proper, the results are often surprising and indicate very clearly that the factor of safety in joints is seldom comparable.

For operating voltages up to about 15 kv. almost any kind of joint is satisfactory, provided the dimensions are reasonable and the degree of filling and grade of materials and workmanship are reasonably good. As the voltage increases, more attention must be paid to fundamental principles, the design dimensions and dielectric stress field more scientifically proportioned, the grade and types of material more carefully chosen, and the process selected to give the best assurance that moisture and voids will be reduced to a minimum.

In the above respects much could be contributed by engineers who have developed high tension bushings. The principles are identical, although the conditions are somewhat different, being altogether in favor of bushings. For a given value of voltage, say 66 kv., single-conductor cable joint design is more difficult than bushing design. Three-conductor design is correspondingly more difficult. One reason for this is the relatively high stressing of cables. This is all very well over the cable length, proper, but at the ends where the joints must be placed it introduces an undesirable factor. If it were practicable, during the process of manufacture, to flare out the ends of cables by increased thickness of insulation, many of the joint problems would be eliminated.

Most of the high voltage joints in this country are filled with soft, or even liquid, compounds. The defects of hard compound fillers for high voltage work are generally recognized. The lateral weakness of paper wrappings, a very important factor in cable joints, is also recognized and various methods are used to overcome this.

There is a very decided lack of satisfactory methods of testing and comparing joints during investigative work. Dielectric strength tests of either long or short duration tell only part of the story. Dielectric loss and high voltage direct-current tests are being studied to determine their value. Microphone listening devices for detection of internal discharge have proved helpful.

End bells have been purposely left out of this discussion. Their problems parallel joint problems closely and being somewhat easier are best served by centering attention on joints.

Dielectric Strength

Three important rules have been established concerning dielectric strength of paper cables:

1st. The paper and compound must be free of all impurities, especially moisture.

2nd. All interstices between and around the cellulose fibers and throughout the cable cross section must be completely filled with compound, leaving no voids or air spaces.

3rd. The cellulose fibers act as very effective barriers and the largest possible number should be interposed along the dielectric path.

The pyro-electric, or conduction, theory of breakdown as developed by Dr. Wagner[1] and others is generally accepted as agreeing closely with observations.

Additional light has been thrown on dielectric strength by Mr. Wiseman's[2] recent paper and the discussion which followed. Instead of assuming that dielectric strength is a function of maximum, minimum, or average stress, he tends to show that it is best expressed by an empirical formula similar to that for corona in air A formula of this nature is more in line with Dr. Wagner's conduction breakdown theory, and with observed facts.

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[1] "Physical Nature of Electrical Breakdown of Solid Dielectrics," K. W. Wagner, Journal A.I.E.E., December, 1922.

[2] "The Apparent Dielectric Strength of Cables," R. J. Wiseman, Journal A.I.E.E., February, 1923.

The Cable Research Committee is apparently working towards the establishment of a definitely required ratio between breakdown voltage, as determined by standard dielectric strength tests, and operating voltage. According to present information this ratio should be somewhere between 3 and 4. It would seem logical to also establish a ratio between breakdown voltage and standard high potential acceptance and installation tests. This would give the best assurance that cable was not injured during these tests.

Dielectric strength tests are becoming increasingly difficult, requiring extremely high voltage test equipment and special end bells.

Internal Ionization

The consensus of opinion seems to be that ionization will become of more importance as voltage rating increases and, that with the present voltage ratings and thicknesses of insulation, there is little to fear from this cause. Referring to the data in Table I, it will be seen that cables are now operating at stresses from 30 to 48 kv. per cm., somewhat higher than the values now derived from ionization tests in the laboratory on short lengths.

Ionization has been investigated for a number of years with little success in placing the results upon a qualitative working basis. Apparently, laboratory tests are of no use as a guide to operating performance. Systematic field tests would be necessary. Certain principles, such as complete filling and avoidance of contraction and expansion troubles, have been emphasized, however, by this work.

Heating of Cables

The Second Report, on the "Heating of Buried Cables," was recently presented before the I.E.E. by the British Research Association. It is a very remarkable and valuable report, representing a tremendous amount of work and a complete summary of present knowledge on the heating of cables. Among the more interesting results are the following:

TABLE II
Temperature Limits for Paper Cables

Buried Cable

German—50 deg. C. (ambient soil 25 deg. C.)

French—50 deg. C. (ambient soil 10 deg. C.)

British—65 deg. C. (ambient soil 15 deg. C.)

(to 11,000 volts only, presumably lower temperature for higher voltages)

Cables in Ducts

British—50 deg. C. (ambient soil 15 deg. C.)

(to 11,000 volts only)

American—85 deg. C—E (where E is line kilovolts)

In the above table the British limit the temperature for duct operation to a lower value due to possible abrasion of sheath from contraction and expansion.

Thermal resistivity of soil 340 to 90 for different degrees of moisture content.

Thermal resistivity of paper cables 750 average up to 2200 volts and 550 average up to 11,000 volts.

Example of grouping two equally loaded cables (buried):

Distance between axis inches	Reduction permissible current (ratio)
4	0.76
8	0.82
12	0.86

Three-conductor ,0.15-sq. in., 11,000-volt cable, 220 amperes (dielectric loss negligible):

ONE CABLE

	Buried	In air	In duct
Temp. rise	25 deg. C.	31 deg. C.	36 deg. C.

Ratio of temperature rise of one three-conductor, 0.2-sq. in. cable buried and in air for average soil conditions (G = 120):

	3300 Volt	11,000 Volt	22,000 Volt
Ratio	1.13	1.09	1.04

Ratio of temperature rise, three-conductor cable, in duct and in air, for average soil conditions, 0.98 to 0.94 for different size cable.

In reference to above paragraph the British findings would indicate that this ratio is not affected by soil conditions, because of the greater influence exerted by the layer of air surrounding the cable. This does not agree with experience in this country, where moisture in the soil has been proved to have a decided cooling effect

The British Report contains some very valuable loading tables for all conditions and types of cables. American practice in ducts now strictly avoids grouping excessive numbers of cable, and aims towards exposing at least one side of each duct to the earth. Grouping low and high voltage cables in the same duct bank is avoided as far as possible, and where it must be done the high voltage cables are placed in the most favorable outside ducts. Artificial cooling by forced ventilation, soaking of soil with moisture, etc., is employed where conditions make it necessary.

Operating and manufacturing companies in this country have individually contributed a great deal towards this problem of heating, but the work was not properly organized and the individual efforts did not co-ordinate. The Cable Research Committee is undertaking a serious program along these lines. If they are given whole hearted support much can be accomplished.

A great deal more information is needed on grouping of cables, thermal resistivity and capacity, heating due to fluctuating loads, best methods of cooling, effects of contraction and expansion, etc.

Short Circuit Heating

Heating of cables from short circuit current has not received the attention it deserves. Reactors are used to limit short circuit more in the interest of transformers and station apparatus.

English writers state that they do not experience contraction and expansion troubles in cable because they limit the loading temperature to a safe value. They lose sight of the fact that one or two short circuits, lasting only a few seconds, might undo years of conservatism of loading temperature.

The whole question is, what temperatures are reached in cables under short circuit? One of the manufacturing companies has started work on this problem. Indications are that short circuit 33 times normal for a period of five seconds (not an uncommon condition) will cause, for a short duration of time, copper temperatures several times that allowed by limiting rules.

It may be that as the work progresses features will be brought out showing that ordinary short circuit is not very harmful, on the other hand it might prove a very important factor. Its possibilities are pointed out constructively, with no spirit of pessimism.

Testing Cable with High Direct-current Voltage

One of the outstanding cable developments of the past year was described in a paper presented before the Institute by Messrs Phelps and Tanzer.[3] By use of the kenotron as a source of high potential direct current they have developed a routine test which serves to detect incipient faults in cable lines. Insulation resistance versus time (absorption) curves are taken periodically and trouble detected by peculiarities in the shape of these curves. They have been very successful in detecting and weeding out incipient troubles in 6.0-kv. and 13.2-kv. three-conductor cable lines with direct-current test voltages, respectively, of 9.0 kv. and 15.0 kv.

This method is being tried out on other cable systems up to 33-kv. rating with promising results. The experiments are not yet far enough advanced to say that this method is universally applicable. The principle is correct and it is hoped, in time, that it will be the means of reducing all cable short circuits to a negligible figure.

Direct-current voltage is also a useful substitute for alternating-current voltage in high potential testing of long cable lines.

The ratio between direct-current and alternating-current test voltage has been the source of much study. At the present time, at least one of the cable companies is accepting a ratio for paper insulated cables of 2.4 at 25 deg. C. with a reduction of 0.0125 in ratio for each deg. C. increase in temperature. The Institute is working towards the adoption of Standard Rules covering direct-current testing.

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[3] "A New Method for the Routine Testing of High Voltage Cable," by H. S. Phelps and E. D. Tanzer, Journal A.I.E.E., March, 1923.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted, which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alternators

Some Problems in High-Speed Alternators, and Their Solution. Rosen, J.
I.E.E. Jour., Apr., 1923; v. 61, pp. 439-476.

Balancing

Balancing of Turbo-Alternator Rotors. Bellisson, J. (In French.)
Revue Gén. de l'Elec., Apr. 28, 1923; v. 13, pp. 693-702.
(Presents a method for which a great saving in time is claimed.)

Carrier-current Communication

Baltimore-Holtwood Carrier Current Giving Excellent Service.
Elec. Wld., May 12, 1923; v. 81, pp. 1077-1081.
(An account of tests conducted on a 40-mile length of the Pennsylvania Water & Power Company's lines.)

Electric Cables

Cable Geometry and the Calculation of Current-Carrying Capacity. Simons, Donald M.
A.I.E.E. Jour., May, 1923; v. 42, pp. 525-539.
(Design calculations for underground cables.)

Electric Furnaces

Some Problems in Electric Furnace Operation. Andreae, F. V.
A.I.E.E. Jour., May, 1923; v. 42, pp. 498-509.
(Mathematical discussion of the design of three-phase furnaces.)

Electric Locomotives

Fuel Consumption of Oil Burning Locomotives. Babcock. A. H.
Rwy. Mech. Engr., May, 1923; v. 97, pp. 265-267.
(Paper before the A.I.E.E. Methods used and results obtained in a test on the Southern Pacific Railroad to determine the relative efficiency of oil burning and electric locomotives. Serial.)

Electric Transmission Lines—Towers

Double-Circuit Tower Construction. Sharp, H. L.
Elec. Wld., May 19, 1923; v. 81, pp. 1133-1135.
(Design, erection and cost information on towers for a 110,000-volt line constructed by the Niagara, Lockport & Ontario Power Company.)

Hydroelectric Plants, Automatic

Full-Automatic Hydro-Electric Station. Collins, E. B.
Elec. Wld., May 19, 1923; v. 81, pp. 1143-1147.
(Description of a 5000-kv-a. plant installed by the New England Power Company at Searsburg, Vt.)

Reactors

Neutral Grounding Reactor. Lewis, W. W.
A.I.E.E. Jour., May, 1923; v. 42, pp. 467-484.
(Discusses tests made on the Peterson coil installation on the Alabama Power Company's system.)

Ship Propulsion, Electric

Electric Propulsion of Ships. Johnson, R. S.
Shipbuilder, May, 1923; v. 28, pp. 360-366.
(Abstract of paper before the Liverpool Engineering Society.)

Steam Plants

Benson Super-Pressure Plant, Swain, P. W.
Power, May 22, 1923; v. 57, pp. 796-801.
(Describes an experimental boiler installation for a pressure of 3200 lbs., which is being erected in the Rugby plant of the English Electric Company, Ltd.)

Problems in Steam Plant Operation. Quinn, E. A.
Jour. Elec. & West. Ind., May 15, 1923; v. 50, pp. 370-377.
(From a report of the Prime Movers Committee of the Pacific Coast Electrical Association.)

Steam Turbines—Governing

Steam-Turbine Governors and Valve Gears; Adjusting Speed and Speed Regulation. Thompson, Eustis H.
Power, May 22, 1923; v. 57, pp. 790-795.

Substations, Automatic

Discussion of Application and Economics of Automatic Railways Substations. Bale, L. D.
A.I.E.E. Jour., May, 1923; v. 42, pp. 439-444.

Maintenance of Voltage on a D-C. Distribution System by Means of a Fully Automatic Substation. Robinson, P. J.
I.E.E. Jour., Apr., 1923; v. 61, pp. 417-438.
(Describes an installation in Liverpool, England, used to operate a three-wire system.)

Switches and Switchgear

Automatic Switch-Reclosing Apparatus. Middlemiss, G. H.
Elec. Wld., May 19, 1923; v. 81, pp. 1150-1152.
(Illustrated description of apparatus developed by the Alabama Power Company.)

NEW BOOKS

Four Lectures on Relativity and Space. Steinmetz, Charles P. 126 pp., 1923, N. Y., McGraw-Hill Book Co., Inc.

Industrial Furnaces. Vol. 1. Trinks, Willibald. 319 pp., 1923, N. Y., John Wiley & Sons.

Printing Telegraph Systems and Mechanisms. Harrison, H. H. 435 pp., 1923, N. Y., Longmans, Green & Co.

X-Rays. Ed. 4. Kaye, G. W. C. 320 pp., 1923, N. Y., Longmans, Green & Co.

GENERAL ELECTRIC REVIEW

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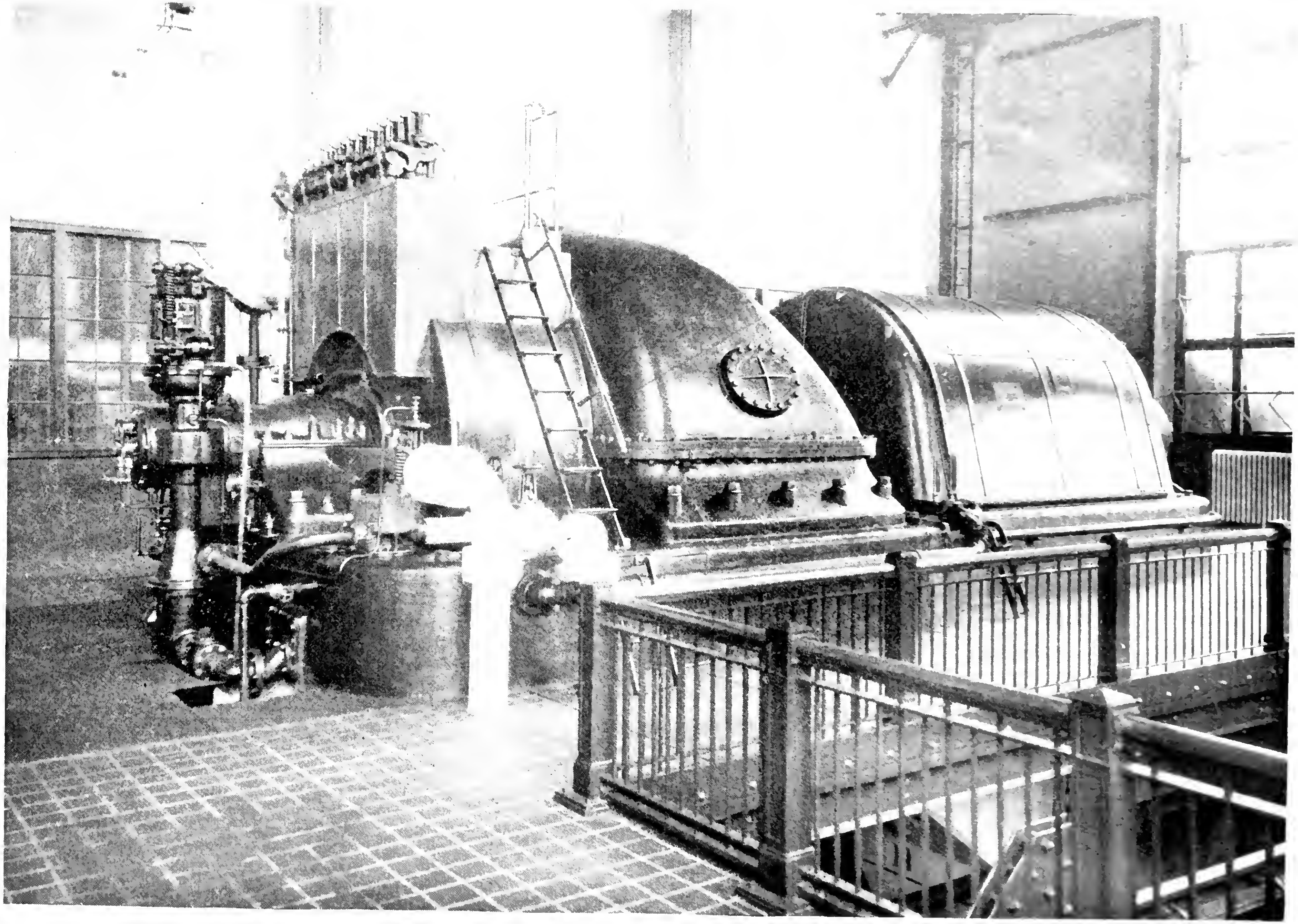

18,750-kv-a. Turbine-generator Installed in the Amsterdam Steam Plant of the Adirondack Power and Light Corporation. In this issue we conclude a series of articles by A. R. Smith on the Cooling of Turbine Generators, and it is of interest to note that the above unit is equipped with a General Electric surface type air cooler

GENERAL ELECTRIC REVIEW

NATURE'S LAWS

A twentieth-century engineer would feel somewhat bewildered if suddenly transplanted back into a pre-Newtonian world. If he were asked to perform the simplest calculation in mechanics, such as today a high school boy would, we hope, do with ease, his embarrassment would be complete. It is quite hard and requires a good deal of imagination to put ourselves in the position of this embarrassed engineer. Let him attempt the solution of any common everyday problem which requires an elementary knowledge of mechanical laws and metaphorically speaking he would flounder about like a flat fish out of water.

Newton, among his many other notable contributions to our knowledge of the natural laws which govern the world we live in, and, indeed, the universe, propounded the laws of motion. This single contribution to our knowledge gave new light to thousands of minds and enabled them to do new work for the benefit of mankind of which they were utterly incapable before.

The progress that the world makes, owing to the work of one such genius, is incalculable, but there were many men in Newton's time who did not realize that his genius had given the world a new epoch.

We have tried to make our readers see how bewildered an engineer today would be if he had not the knowledge that Newton gave the world, and we feel that it is time for engineers to realize that they will be sadly bewildered in the near future if they do not have at least some understanding of the work that Sir Joseph John Thomson has done in recent years. If we perceive things correctly, Sir Joseph John Thomson has shown the orderliness of Nature's laws down to the very minutest of all things. He has done more than given us knowledge of one law in giving us knowledge of the structure of the atom—he has given us knowledge of the structure of all things and opened up a host of new realms for man's imagination and skill to work in.

The fruit that his work and the work of others, stimulated by his great lead, will bear in the next ten, twenty or thirty years is absolutely impossible to contemplate. But there is little doubt that with our large industrial research laboratories of today, whose function it is to take this new knowledge in the realm of science and turn it to practical everyday use in the realm of commerce, we shall be using this new knowledge extensively in everyday engineering practice in the very near future.

It is for this reason that we see the imperative necessity of the engineer trying to understand the work that J. J. Thomson, Rutherford, Bragg and others have done and why we feel there is no apology needed for publishing in our pages the scientific theories that are destined to govern future engineering practice.

It is with these thoughts in mind that we asked the Editor of the Journal of the Franklin Institute for permission to publish the lectures recently given in America by Sir Joseph John Thomson on the Electron in Chemistry. We publish the first of these lectures in this issue. J. R. H.

The Electron in Chemistry

PART I

By Sir Joseph John Thomson

Master of Trinity College, Cambridge, England

Sir Joseph John Thomson gave a series of lectures before the Franklin Institute, April 9 to 13, 1923, on the Electron in Chemistry. Believing that these lectures are of great value to the entire scientific and engineering profession in showing what the scientist is doing today to stimulate engineering developments in the future, we asked the Editor of the Journal of the Franklin Institute for permission to reprint these lectures in the Review. We wish to acknowledge with gratitude the granting of this permission. Our present contribution appeared in the May issue of the Journal of the Franklin Institute.—Editor.

I ought to explain why it is that I, who am a physicist and not a chemist, have chosen chemistry as the subject of these lectures. I have done so because I believe that the introduction of the idea of the electron will break down, and indeed has already done so to some extent the barrier of ignorance which has divided the study of the properties of matter into two distinct sciences, physics and chemistry. The properties of matter which are of primary importance to the chemist are those which relate to the power of atoms to unite together to form new combinations, new compounds. The ability to do this and the type of compound formed vary enormously from one chemical element to another. Until recently the conception formed by the physicist of the atom afforded no clue to this variation in the chemical properties of the atom and gave therefore but little guidance to the chemist in what he regarded, and quite rightly, as the most important part of his work. The chemist wants to know much more about the difference between an atom of hydrogen and one of oxygen than that the atom of hydrogen is a small particle of one kind of matter and the atom of oxygen a heavier particle of another kind of matter. This lack of knowledge led to a proposal made by a distinguished chemist at the beginning of this century to give up the atomic theory and base chemistry on statistical and thermodynamical considerations.

The chemist wants to know the reason why the behavior of an atom of hydrogen is so different from that of one of oxygen. This must depend upon the differences in the constitution of the two atoms themselves. Thus to explain the difference between the chemical properties of different atoms we have to go a stage further than the atomic theory. Just as some of the physical properties of matter in bulk had required for their explanation the conception that matter is not continuous but has a structure of finite and measurable fineness, so no progress could be made towards the explanation of their chemical properties until we gave up the idea that the atom was indivisible, continuous and uniform, and assigned to atoms as well as to solids and liquids a structure of their own. The discovery of the electron in 1897 was the first direct evidence of such a structure. It was shown that these electrons came from all types of atoms, and that whatever the source there was only one kind of electron, which has a mass only about 1/1700 that of an atom of hydrogen and carries a charge of negative electricity numerically equal to the positive charge associated with an atom of hydrogen in the electrolysis of solutions.

Thus an invariable electron was proved to be a constituent of all atoms. Means were then devised to measure the number of electrons in the atoms of the different chemical elements. It was found that this number was finite and varied from element to element, and that the number of electrons in the atom of an element was equal to the atomic number of the element: The atomic number of an element being its place in the list when the elements are arranged in the order of their atomic weights. As the atomic number is roughly proportional to the atomic weight the proportion between the mass of the electron and the total mass of an atom is, except for hydrogen, much the same for all atoms. The electrons, however, only account for about 1/3400 of the whole mass, for most purposes a negligible fraction.

The greater part of the mass is accounted for by the positively electrified part of the atom. The electrons are all negatively electrified and as the normal atom is electrically neutral, there must be within it a positive charge to balance the negative one on the electrons. This positive charge, as experiments on positive rays show, is attached to a mass equal to the mass of the atom. Thus the carrier of the positive charge, unlike that of the negative, varies from element to element. As the mass of the positive charge is always an integral multiple of a unit, it is natural to suppose that this mass is made up of a number of units bound together. The number of such units is equal to the atomic weight and the number of electrons approximately half that number, if each unit of mass carries the atomic charge of positive electricity, the quantity of positive electricity would be too large unless these positive units were associated with about half this number of electrons. Thus, in addition to the structure conferred by the electrons, the positively electrified parts have themselves a structure, it is the structure conferred by the electrons which is responsible for the chemical properties of the atom, the structure of the positive core is concerned with radioactive transformations.

As up to the present nothing has been discovered that cannot be resolved into electrons and positively electrified particles, it is natural to frame a theory of the structure of the atom on the supposition that it is built up of these two ingredients. It should be borne in mind, however, that our means of detecting the existence of electrically charged bodies far surpass those for detecting uncharged ones, and if there were any uncharged constituents of the atom, they would in any case probably have escaped detection. We know, however, even supposing that such constituents do exist, their mass must be negligible compared with that of the positive parts, for these parts account for well within a fraction of a per cent of the whole mass of the atom.

Arrangement of Electrons in the Atom

Confining ourselves then to the consideration of things whose existence has been demonstrated we regard the atom as made up of a massive positively electrified center surrounded by electrons: The number of electrons increasing from one in the atom of hydrogen to a hundred or more in the heavier elements. The positive charge of the center and the negative charges on the electrons will produce a field of electrical force which will be determinable when the position of the electrons can be specified. Thus the force exerted by the atom and therefore its chemical properties will depend upon the configuration of the electrons and to determine this is one of the most important problems in the electron theory of chemistry.

This problem is that of determining the way the electrons will arrange themselves under the action of their mutual repulsions and the forces exerted upon them by the positive charge.

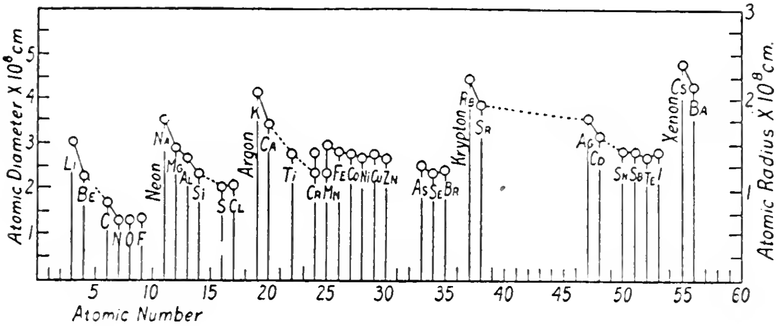

Fig. 1

In the first place we observe that if these forces were to vary strictly as the inverse square of the distance we know by Earnshaw's theorem that no stable configuration in which the electrons are at rest or oscillating about positions of equilibrium is possible, the electrons must describe orbits, and further they must describe different orbits; for such a system as that in Saturn's rings where several units follow each other round the same orbit is not possible when the units, as the electrons would do, repel each other instead of attracting one another like the constituents of Saturn's rings. When there are several electrons in the atom the orbits described by the electrons would be of great complexity, and the mental picture conveyed by this multitude of orbits would be too blurred and complicated to be of much assistance in helping us to get readily a clear idea of what is going on in chemical processes.

I have therefore adopted the plan of supposing that the law of force between the positive part and the electrons is, at the distances with which we have to deal in the atom, not strictly that of the inverse square, but a more complex one which changes from attraction to repulsion as the distance between the positive charge and the electron diminishes. This hypothesis leads to a simple mental picture of the structure of the atom and its consequences are in close agreement with the facts of chemistry. I suppose that the repulsive force between two *electrons* is always inversely proportional to the square of that distance. With regard to this point I may point out that we have no direct evidence as to what may be the law of force between electrical charges at distances comparable to 10^{-8} cm., which is a distance we have reason to believe is comparable with that which separates the positive charge from the electron in the atom. The direct experimental verification of this law has been of course made at incomparably greater distances, while the direct experiments, such as those on the scattering of the alpha particles, only give information as to the law at distances very small compared with 10^{-8} cm.

I shall assume that the law of force between a positive charge and an electron is expressed by the equation

$$F = \frac{Ec}{r^2}\left(1 - \frac{c}{r}\right) \tag{1}$$

where F is the attraction between the charges, E, e, the positive and negative charges on the core and electrons, respectively, r the distance between them and c is a constant varying from one kind of atom to another, it is the distance at which the force changes from attraction to repulsion and is of the order of 10^{-8} cm.

We may remark in passing that the introduction of some new physical law, involving directly or indirectly a length of this order, is necessary for any theory of the structure of atoms. We could not form a theory at all if all we knew about the action of electric charges was that they repelled or attracted inversely as the square of the distance, for this would put at our disposal only two quantities, the mass of an electron and its charge, and so could not furnish the three units of space, mass and time required for any physical theory. The discovery of the induction of currents or what is equivalent, the magnetic effect due to electric charges, introduced another fundamental unit, the velocity of light; the unit of length to which this system leads is the radius of the electron, about 10^{-13} cm., a quantity of quite different order from 10^{-8} cm., which corresponds to atomic dimensions. The size of atoms being what it is, is a proof that there is some law of physics not recognized in the older science which is all-important in connection with the theory of the atom and must form the basis of that theory.

If the law of force is that just given, then a number of electrons can be in stable equilibrium around a positive charge without necessarily describing orbits around it.

One Electron Atom

Thus, for example, if there is one electron it will be in stable equilibrium at a distance c_1 from the positive charge.

Two Electron Atom

If there are two electrons they will be in equilibrium with the positive charge midway between them, r the distance of either electron from the positive charge is given by the equation

$$\frac{Ec}{r^2}\left(1 - \frac{c_2}{r}\right) = \frac{c^2}{4r^2} \tag{2}$$

When the positive charge and the two electrons form an electrically neutral system $E = 2e$, so that $c_2/r = 7/8$ or $r = 1.14\ c_2$.

Three Electron Atom

When there are three electrons, they will be in equilibrium at the corner of an equilateral triangle with the positive charge at the center. r, the distance of any electron from the center, is given by the equation

$$\frac{Ec}{r^2}\left(1 - \frac{c_3}{r}\right) = \frac{2}{3r^2}\cos 30 \tag{3}$$

When the system is electrically neutral $E = 3e$, so that $r = 1.26\ c_3$.

Four Electron Atom

The most symmetrical arrangement of four electrons is when they are at the corners of a regular tetrahedron. The distance of the electrons from the center when the atom is neutral is equal to 1.29 c_4. The tetrahedron may be regarded as the ends of two equal lines at right angles to each other and also to the line joining their middle points.

Five Electron Atom

Five electrons are in equilibrium when arranged so that three are at the corners of an equilateral triangle, the other two at the ends of a line passing through the center of the triangle and at right angles to its plane; the line is bisected by the plane of the triangle. The distance of the electrons in the triangle from the center is 1.34 c_5, that of the other two 1.37c_5.

Six Electron Atom

Six electrons are in equilibrium when at the corners of a regular octahedron. For some purposes it is convenient to regard the octahedron as two equilateral triangles at right angles to the line joining their centers, one triangle being twisted relatively to the other so that the projection of their corners on a parallel plane forms a regular hexagon. The distance of the electrons from the center is 1.38 c_6.

Seven Electron Atom

Seven electrons arrange themselves so that five are at the corners of a regular pentagon while the two others are at the ends of a line through the center at right angles to the plane of the pentagon and which is bisected by that plane. The distance of the electrons in the pentagon from the center is 1.4 c_7, that of the other two 1.37 c_7.

TABLE I

Two-dimensional Problem

$n = 1$	2	3	4	5	6	7	10	12	14	16	8
$E/e > 0$	.75	1.58	3.10	4.76	7.32	14.2	24.48	38.9	58	83	115

Three-dimensional Problem

$n = 1$	2	3	4	6	8	12	20
$E/e > 0$	.75	1.58	2.44	4.8	7.6	13	30

Eight Electron Atom

Eight electrons arrange themselves at the corners of a twisted cube, a figure obtained by taking two squares, placing them parallel to each other and at right angles to the line joining their centers, and twisting them relatively to each other so that the projection of their corners on a parallel plane forms a regular octagon.

Configuration when the Number of Electrons is Greater than Eight

The following considerations show, however, that there must come a stage when it will no longer be possible to have all the electrons at the corners of a regular polyhedron.

To keep the electrons in stable equilibrium in spite of their mutual repulsion requires a finite positive charge and the greater the number of electrons and therefore the smaller the angular distance between an electron and its nearest neighbor, the greater the positive charge must be.

In Table I, I give the results of a calculation of the positive charge E required to keep n electrons in stable equilibrium. The first line refers to the two-dimensional problem, when the electrons are arranged at equal intervals round the circumference of a circle with a positive charge at the center; the second line refers to the three-dimensional problem when the electrons are at the corners of a polyhedron.

These numbers are for a law of force between the positive charge and the electron represented by $\frac{Ee}{r^2}\left(1-\frac{c}{r}\right)$. If the part of the force which does not vary inversely as the square of the distance varies inversely as some higher power than the cube, then the number of electrons which a given positive charge can keep in stable equilibrium will be increased.

Confining ourselves for the moment to the case when the force is represented by

$$F = \frac{Ee}{r^2}\left(1-\frac{c}{r}\right)$$

we see from the second table that when the number of electrons is not greater than eight, the electrons can be kept in equilibrium by a positive charge equal to the sum of the negative charges on the electrons, which is the greatest positive charge which can occur in a neutral atom. So that when the number of electrons is not greater than eight, a neutral atom can have these electrons arranged symmetrically at the same distance from the center at the corners of a regular polyhedron. When, however, the number exceeds eight this is no longer possible. For we see from the table that to keep, say, nine electrons in stable equilibrium would require a positive charge more than $9e$, where e is the charge on an electron, but in a neutral molecule $9e$ is the maximum positive charge available when there are nine electrons in the atom. Thus the regular progression in the arrangement breaks down when the electrons amount to eight and a new arrangement must come into force. Let us suppose that there are nine electrons; then these nine cannot all be arranged at the same distance from the center, for this arrangement would be unstable since a positive charge of nine is insufficient to keep nine electrons in stable equilibrium. The charge $9e$ could, however, keep eight electrons in stable equilibrium at the same distance from the center, leaving one to go outside. The distance of the eight electrons from the central charge would be 1.38 c_9, that of the single electron would be 9 c_9. So that the single electron would be a long way out from the center of the atom.

If there are ten electrons, these can be arranged so that eight form a layer round the center and two go outside, the distance of the eight from the center would be 1.33 c_{10}, that of the two outlying ones would be 5.7 c_{10}.

Eleven electrons can be arranged with an inner layer of eight and an outer one of three, the distance of the inner one from the center would be 1.3 c_{11}, that of the outer one 4.625 c_{11}.

Twelve electrons might be arranged with an inner layer of eight, radius 1.26 c_{12} and an outer layer of four, radius 3.9 c_{12}.

Thirteen electrons, with an inner layer of eight, radius 1.227 c_{13} and an outer layer of five, mean radius 3.52 c_{13}.

Fourteen electrons, with an inner layer of eight, radius 1.22 c_{14}; and an outer layer of six, radius 3.22 c_{14}.

Fifteen electrons, with an inner layer of eight, radius 1.2 c_{15}; an outer layer of seven, mean radius 3.1 c_{15}.

Sixteen electrons, with an inner layer of eight, radius 1.18 c_{16}; an outer layer of eight, radius 2.9 c_{16}.

We have now got eight electrons on the outer layer and there is not accommodation for any more; for since the atom is neutral the excess of positive over negative electricity in the system consisting of the central charge and the inner layer is equal to the charge on the electrons in the outer layer, thus if there were nine electrons in the outer layer there would be only an effective positive charge of nine to keep them in equilibrium. We can, however, get a system which will be in stable equilibrium if the electrons proceed to form a third shell; thus, if there are seventeen electrons, we could have an inner shell of eight, then another shell of eight and then an electron a long way outside. If we had eighteen electrons we should get two shells of eight and two electrons outside, and so on, until with 24 electrons we shall have filled up the third shell and have to begin again.

Let us now arrange the lighter elements in the order of the number of electrons they contain, and place underneath the symbol for the element the number of electrons in the outer layer of the atom. The number of free electrons in the atom has been taken as two less than the atomic number of the element, since two electrons always seem to cluster round the center core and form a system by themselves.

TABLE II

	Li	Be	Bo	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	A	K
Number of free electrons in the atom...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Number of electrons in the outer layer.....	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1

The Periodic Law

Thus, if we arrange the elements in the order of the number of electrons in the atom, which we have seen is the same as the order of the atomic weights, there will be a periodicity in the number of electrons in the outer layer. It will increase from one to eight, then drop again to one; increase again to eight, drop to one, and so on. Thus, as far as properties depending upon the outer layer are concerned, the elements will show a periodicity in their properties similar to that expressed by Mendeleef's periodic law in chemistry.

We shall show later on that the valency is a property depending on the number of electrons in the outer layer, the electropositive valency being proportional to that number, so that this type of atom would explain the periodic law.

Variation of the Number of Elements in a Period

We have supposed that when the positive charge and therefore the number of electrons in the atom is increased by unity, the additional electron goes to the outer layer. This need not, however, necessarily be the case. When the positive charge is increased, the number of electrons which it can hold in stable equilibrium on a spherical layer with its center at the atom increases also; thus a large positive charge at the center could hold more than eight electrons in the inner layer, and so the additional electron might, instead of going to the outside, find accommodation on one of the inner layers. Thus, since the valency depends on the number of electrons in the outer layer, if the additional electron was trapped in an inner layer, two consecutive elements, though they would have different atomic weights, would have the same valency. When there are a large number of electrons in the atom arranged in many layers it may require the addition of several electrons to the atom before there is any increase in the number in the outer layer and thus there might be a considerable number of adjacent elements with different atomic weights but with very similar chemical properties. There are groups of elements such as iron, nickel and cobalt group, the rhodium group, the crowd of elements known as the rare earths, and the platinum group which fulfill this condition.

TABLE III

POTENTIAL ENERGY OF ATOMS WITH THREE TO EIGHT ELECTRONS

Arrangement of Electrons	Distances of Electrons from Atom	Potential Energy
Eight Electrons		
(i) One layer—twisted cube	1.447 c	$-16.75\ e^2/c$
(ii) One layer—cube	1.446 c	$-15.28\ e^2/c$
(iii) Two layers—tetrahedra similarly orientated	1.105 c (4) 3.108 c (4)	$-14.77\ e^2/c$
(iv) Two layers—six electrons in inner, two in outer ring	1.282 c (4) 1.267 c (2) 4.80 c (2)	$-15.012\ e^2/c$
Seven Electrons		
(i) One layer	1.37 c (2) 1.439 c (5)	$-12.181\ e^2/c$
(ii) Two layers—five in inner, two in outer ring	1.244 c (3) 1.191 c (2) 4.316 c (2)	$-12.096\ e^2/c$
Six Electrons		
(i) One layer	1.385 c	$-9.40\ e^2/c$
(ii) Two layers—four in inner, two in outer ring	1.196 c (4) 3.55 c (2)	$-8.868\ e^2/e$
Five Electrons		
(i) One layer	1.342 c (3) 1.376 c (2)	$-6.806\ e^2/c$
(ii) Two layers—four in inner, one in outer ring	1.273 c (3) 1.134 c (1) 5.105 c (1)	$-6.667\ e^2/c$
Four Electrons		
(i) One layer—corners of square	1.298 c	$-4.748\ e^2/c$
Three Electrons		
(i) One layer—equilateral triangle	1.238 c	$-2.934\ e^2/c$
(ii) Electrons on a straight line through atom	1.087 c 1.035 c 3.577 c	$-2.787\ e^2/c$

Allotropic Forms

There is in general more than one way in which the electrons can be arranged in stable equilibrium and though one particular arrangement may have the absolute minimum potential energy, yet calculation shows that in some cases the difference in potential energy between this configuration and some other one is exceedingly small and changes in the surroundings change the balance in favor of one or the other. If these configurations have different numbers of electrons in the outer layer, then they would correspond to forms with different valencies, and thus we may look in this direction for an explanation of the variable valencies shown by some elements. We shall return to this point later on.

Table III, calculated by Miss Woodward, gives in the third column the potential energy corresponding to the various arrangements of the electrons in atoms containing from three to eight electrons. The second column contains the distances of the electrons from the center of the atom. Thus the figures corresponding to the arrangement of seven electrons in a double triangular pyramid with two electrons outside on the axis of the pyramid, indicate that the electrons on the triangular base are at a distance 1.244 c from the center; those at the vortex of the inner pyramid at the distance 1.191 c while the outer electrons are at a distance 4.316 c.

A simple example of the small difference in the potential energy between different configurations is afforded by an atom containing five electrons. We have described one such configuration when the five electrons were approximately at the same distance from the center. There is, however, as we see from the table, another arrangement where four electrons are at the corners of a regular tetrahedron with its center at the positive charge, while the fifth electron is a long way outside the tetrahedron. The mean distance of the electrons on the tetrahedron from the center is approximately 1.22 c_5; where c_5 is the value of c for the fifth electron atom, while that of the outside electron is approximately 5 c_5, *i.e.*, more than four times greater. The potential energy of the second configuration is only about two per cent greater than the first, thus there would be no great tendency for the second configuration to pass back to the other. The properties of the two configurations would, however, be quite different, in the second configuration we have a single electron far away from the others; this, as we have seen; is also the case with the alkali metals; in this configuration the five electron atom might be expected to show some of the properties of a monovalent element, in the other it would be pentavalent.

Active Nitrogen

As nitrogen has an atom with five disposable electrons, it seems possible that the active form of nitrogen discovered by the present Lord Rayleigh may have this configuration. This active form is produced by passing an electric discharge through nitrogen and it is clear that if an atom were first ionized by the detachment of an electron the conditions would be favorable for the production of the configuration under consideration. For when the first electron is detached the remaining four will naturally arrange themselves in a tetrahedron round the center, thus the nucleus of the configuration is already there and an additional electron at some distance from the center would be more likely to take up a position outside than to force itself into the tetrahedron. As the second form has, like the alkali metals, a single electron at a great distance from the center, we should expect that like them it would be attacked vigorously by halogens, and that as the outlying electron would require little work to detach it, this form of nitrogen would be easily ionized; both these properties are characteristic of Lord Rayleigh's active nitrogen.

We see that besides the two forms for the fifth electron atom there are forms for the sixth and seventh electron atoms which differ little in their potential energy in which two electrons are separated from the rest (*e.g.*, oxygen and fluorine). These would tend to be formed if the atoms were ionized so as to lose two electrons and then regain these electrons. As the number of atoms which lose two electrons when the electric discharge passes through a gas is small compared with the number which only lose one, we should not expect these modifications of oxygen and fluorine to be produced so freely as those of nitrogen.

Experimental Evidence as to the Configuration of Electrons in the Atom

We may hope when our sources of Röntgen radiation are more powerful to be able to obtain evidence of this by observing the interference effects produced when Röntgen rays pass through large numbers of neutral atoms. If the orientation of these atoms is a random one we can easily show that the interference of the rays scattered by the electrons will give rise to a series of rings. There will be a separate ring for every different distance between pairs of electrons in the atom. Thus if there were only two electrons there would only be one ring whose radius is proportional to the distance between the two electrons; again in an equilateral triangle there would only be one ring, for the distance between any two electrons is equal to a side of the triangle. If four electrons were at the corners of a regular tetrahedron there would again be only one ring for the distance between any two electrons is equal to a side of the tetrahedron. If, however, the four electrons were at the corners of a square there would be two rings, the radius of one being proportional to a side of the square, that of the other to its diagonal. Arrangement at the corners of a regular octahedron would also give two rings, the radius of one being proportional to the side of the octahedron, the other to the distance between two opposite corners. A cubical arrangement of electrons would, however, give three rings, the radius of one proportional to a side of the cube, that of the second to a diagonal of a face and that of the third to the diagonal of the cube. Evidence of this kind is not, however, available at present.

As we shall see later on, the coefficient of diamagnetism gives on Langevin's theory of diamagnetism, the moment of inertia of the electrons about a line through the center of the atom, this can be made to yield a certain amount of information about the disposition of the electrons, especially if we know from other sources the distance of the outer layer of electrons from the center of the atom.

Evidence Afforded by Positive Rays

More definite information can be got from evidence afforded by the positive rays. Let us first take the case of positively charged atoms. Their positive charge is due to their having lost electrons from the outer layer, now on this theory there is only one electron in the outer layer of the atom of hydrogen and in those of the alkali metals, so that these atoms should not be able to lose more than one electron and therefore should be unable to gain more than one unit of positive charge.

It is remarkable that these are the only atoms which in the positive ray spectra have not been observed with more than one positive charge. On the other hand, other light atoms have more than one electron and thus gain double or treble positive charges.

All such atoms when detected in the positive ray spectrum have been observed with double positive charges and in some cases such as carbon, nitrogen, oxygen with three or four, while as many as seven positive charges have been found in the atom of mercury.

Further confirmation of the views we have been discussing about .the relation between the number of electrons and the property of the atom is afforded by the study of the occurrence of negatively electrified atoms in a gas through which an electric discharge is passing. By the method of the positive rays we are able to detect negatively as well as positively electrified atoms, and we find in this way that some atoms readily acquire a negative charge while others never do so. On the view we are considering, eight is the maximum number of electrons which can exist in the outer layer; as the atom of neon already possesses this number it cannot accommodate another electron and so cannot receive a negative charge. On the other hand, the atom with a similar number of electrons in the outer layer has, as a reference to Table II shows, a superfluity of stability and can therefore accommodate another electron and thus acquire a negative charge. The superfluity of stability is not, however, great enough for them to accommodate two electrons so that we should not expect to find any atoms with a double negative charge.

In the experiments with positive rays the atom of neon which has eight electrons in the outer layer has never been observed with a negative charge, while negative charges are common on atoms of hydrogen, chlorine, carbon and oxygen. No atoms have been observed carrying two negative charges.

It is remarkable that though carbon and oxygen, the neighbors on either side of nitrogen, readily acquire negative charges, nitrogen itself is very rarely observed with a negative charge. It was thought for a long time that the nitrogen atom never carried a negative charge, recently, however, I have observed in more intense discharges a faint line on the positive ray photograph corresponding to the negatively charged nitrogen atom, it is, however, very feeble in comparison with the adjacent lines due to negatively charged carbon and oxygen, respectively. A calculation of the work required to remove the additional electron from a negatively charged nitrogen atom shows that it is very small in comparison with that required to remove the additional electrons from negatively charged atoms of carbon or oxygen, so that a negatively charged nitrogen atom would easily lose its charge and so be difficult to detect.

Again the only negatively electrified atoms we can observe by the positive ray method are those which have previously been positively charged, *i.e.*, those which at one time have lost an electron. If such atoms, when they regain electrons, are in the condition we have ascribed to "active nitrogen" the electrons they regain will be far out from the center of the atom and so would be very easily detached. Thus very few of those atoms could be expected to retain the electrons necessary to give them a negative charge.

There are some other interesting results which follow at once from the view we have taken of the constitution of the atom. The first we shall consider is the change in the chemical properties produced by electrifying the atom. Let us take the oxygen atom as an example, it has six electrons in the outer layer, and we may anticipate the results to be given in the next chapter by saying that its valency is determined by the number of electrons in this layer. When the oxygen atom is positively electrified it has lost one or more electrons. If it is electrified so that it carries one unit of positive charge, the unit of charge being that carried by an electron, it must have lost one electron, so that the atom will only have five electrons in the outer layer, the same number as there are in a neutral atom of nitrogen. Thus, if the valency depends on the number of electrons in the outer layer, the valency of oxygen carrying a unit charge of electricity ought to be the same as that of a neutral atom of nitrogen, *i.e.*, it ought to form the compound OH_3, a compound having the molecular weight 19. This is confirmed by observation with the positive rays, when hydrogen and oxygen are present in the tube, a line corresponding to this molecular weight is frequently observed. Again, if the oxygen atom carries a double positive charge, and observations on the positive rays show that oxygen atoms with this charge are frequent when the electric discharge passes through gases, the atom must have lost two electrons and will be left with only four in the outer layer, the same number as in the outer layer of a neutral atom of carbon; hence the doubly charged oxygen atom ought to have the same valency as neutral carbon, and thus form the compound $(OH_4)++$. This compound would carry a double charge and the ratio of m/e would be 10. I have found[1] in the positive ray, spectrum lines having this value of e/m when both oxygen and hydrogen were in the discharge tube.

Again the atoms of the inert gases which have eight electrons in the outer layer, would, if they acquired one unit of positive charge, have lost an electron and would only contain seven electrons in the outer layer. This is the number in the outer layer of a neutral halogen atom. The positively electrified atoms of the inert gases could thus like the neutral atoms of the halogens combine with one atom of hydrogen and thus the compound NeH would be possible if it carried a unit charge of positive electricity.

The molecular weight of this would be 21 and a line corresponding to a carrier with this molecular weight has been observed by Aston. The neon atom can, as observations on the positive rays show, lose two electrons, in this state it could combine with two atoms of hydrogen, or one of oxygen, the first of these molecules would have the value $m/e = 11$, and the second $m/e = 18$; the first could not be distinguished from the isotope of neon atomic weight 22 with a double charge, and the line due to the second would be identical with that due to water, so that the positive rays could not afford convincing evidence of the existence of these compounds. If we turn to negatively electrified atoms, a negative electrified chlorine atom would have eight electrons in the outer layer, it would resemble the neutral atom of an inert gas and so would not be able to enter into chemical combination. It would seem as if it ought not to be very difficult to determine this point by direct experiment.

The negatively electrified chlorine atom has the same number of electrons as a neutral atom of argon, both having eight in the outer layer. It might therefore be expected to resemble argon not merely in its chemical properties, but also in the nature of its spectrum. The spectra would not be identical for the positive charge binding the electrons together would be greater for argon than for chlorine. The similarity in the arrangement of the electrons might be expected to lead to similarities in the spectra of negatively electrified chlorine atoms and neutral argon atoms. Again, a positively electrified potassium atom has lost an electron and so would contain the same number of electrons as a negatively electrified chlorine atom or a neutral argon one. Thus we should expect the spectrum of positively electrified potassium atoms to show similarities both with that of negatively electrified chlorine atoms and with neutral argon atoms. Professor Zeeman and Mr. Dik[2] have compared the red spectrum of argon, which is the one due to the neutral atom, with the spectrum due to positively electrified potassium atom and have found some exceedingly interesting points of resemblance. It is easier to observe the spectra due to positively electrified atoms than those due to negatively electrified ones, for in the latter case we should have to observe the spectrum they give out on receiving the negative charge, any attempt to stimulate them to luminescence afterwards would probably result in their destruction.

Similarly positively electrified oxygen atoms might be expected to give spectra resembling

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[1] *Proc. Roy. Soc., 101*, p. 290.

[2] *Proc. Amsterdam Akademie, 25*, pt. 3 and 4.

those of neutral nitrogen atoms and positively electrified nitrogen atoms show similarities with neutral carbon atoms.

The Size of Atoms

By the radius of an atom we mean the distance of the electron in the outer layer from the center of the atom. Let E be the central positive charge and

$$\frac{Ee}{r^2}-\frac{c^2C}{r^3} \tag{4}$$

the attraction between this charge and an electron at a distance r, e is the charge on the electron and $eC=cE$ where c is the quantity introduced in the expression for the same force [formula (1)], c is the distance at which the force between the positive charge and the electron changes from attraction to repulsion.

TABLE IV

Element	N	E/e	S_n	r	
Hydrogen	1	1	0	C_H	$a+b$
Lithium	7	1	0	C_{Li}	$7a+b$
Beryllium	9	2	1	$4C_{Be}/7$	$5.14a+.57b$
Boron	11	3	2.3	$4C_{Bo}/9.7$	$4.52a+.412b$
Carbon	12	4	3.66	$4C_C\ /12.3$	$3.88a+.322b$
Nitrogen	14	5	5.2	$4C_N\ /14.8$	$3.78a+.270b$
Oxygen	16	6	6.68	$4C_O\ /17.3$	$3.69a+.23b$
Fluorine	19	7	8.08	$4C_F\ /19.9$	$3.8\ a+.21b$
Neon	20	8	10.1	$4C_{Ne}/21.9$	$3.63a+.182$
Sodium	23	1	0	C_{Na}	$23.\ a+b$

Then for the equilibrium of an electron on the outer layer we have

$$\frac{Ee}{r^2}-\frac{Ce^2}{r^3}=\frac{S_n}{4r^2}e^2 \tag{5}$$

where $S_n=\Sigma\frac{1}{\sin\theta}$, 2θ being the angle subtended at the center of the atom by a pair of electrons and $\Sigma\frac{1}{\sin\theta}$ means that the sum of the values of $1/\sin\theta$ for each pair of electrons is to be taken. We get from this equation

$$r=\frac{C}{\frac{E}{e}-\frac{S_n}{4}} \tag{6}$$

The values of r for the lighter elements are given in the third column of Table IV. The fourth column is the value of r on the assumption that C is a linear function of the atomic weight, given by the equation $C=aN+b$, where N is the atomic weight and a and b constants.

Thus, taking the elements from lithium to neon, we see that the radius of the outer layer is greatest for the light elements and diminishes rapidly at first and then very slowly to the end of the period. When we pass from neon, the last element in this period, to sodium, the first in the next, there is a large increase in the radius. The sodium atom will have a larger radius than the lithium one, the ratio of the two will depend on the ratio of a to b, if a were zero the radii would be equal.

The increase in the radius which occurs at sodium is followed by a continually diminishing radius until we reach argon; when we pass to potassium, the first element in the next period, there is again an increase. The radii of atoms in the same group like ithium, sodium, potassium, or fluorine, bromine and iodine increase with the atomic weight of the element.

The relation between the radius of the atom and the atomic weight is such that the minima radii occur at the ends of the periods and, as in Lothar Meyer's well-known graph, which has been reproduced in almost every text-book of chemistry, not at the middle. Recent experiments have shown, however, that this graph does not accurately represent the relation. Gervaise le Bas[3], says:

1. "There is a periodic relation between the atomic volume and the atomic weight of the elements."
2. "There is a tendency for the atomic volume to diminish in each series as the atoms increase in weight, the smallest occurs in group 7."
3. "There is a general increase in the atomic volumes of each group from series one onwards, that is in the direction of increasing atomic weight."

This is in entire agreement with the results we have just found. The same thing is beautifully shown by the experiments of W. L. Bragg[4] which give a curve (Fig. 1) for

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[3] "Molecular Volumes of Liquid Chemical Compounds," p. 237.

[4] *Phil. Mag.*, *40*, p. 169, 1920.

the atomic radii which in the period from lithium to neon agrees numerically very well with those deduced from the Table IV given above, especially if b is small compared with a. The formula we have given would, unless a were very small compared with b, make the increase in atomic volume from lithium to sodium too great. According to Bragg the value of the sodium atom is only about 1.2 times that of the lithium one. While if the formula could be stretched from one period to another the increase would be much greater unless a were very small compared with b. We shall see later on that the law of the inverse cube only holds within a limited range of r and that beyond a certain distance the force seems to vary as the simple law of the inverse square. An effect of this kind would prevent any large increase in the radius of the atom as we passed from one period to another, and we should expect to find, as is the case, that the agreement between theory and experiment is most marked for the lighter and smaller atom.

Ionizing Potential

Another quantity which has been the subject of a great many experiments is what is known as the ionizing potential. This is the work required to detach an electron from the atom, expressed as the fall of the charge on an electron through this potential. We may remark that the work required to detach the electron must depend upon the way in which it is done, so that the ionizing potential is not a perfectly definite quantity. Thus to take two extreme cases, we may suppose the electron removed so suddenly that the other electrons have no time to change their position before it is out of their range of action, or to take the other extreme we may remove it so slowly that the electrons are always in their position of equilibrium corresponding to the position of the electron which is being ejected. In the first case the work required to move the electron away from the central positive charge is

$$\frac{Ee}{r}-\frac{1}{2}\frac{Ce^2}{r^2}$$

and the work done by the other electrons in ejecting it is $e^2/r_{12}+e^2/r_{13}+e^2/r_{14}$ . . . where r_{12}, r_{13}, r_{14} are the distances of the ejected electrons from the other electrons indicated by the suffixes 2, 3, 4. Now $r_{12}=2r\sin\theta_{12}$ where $2\theta_{12}$ is the angle between the radii from the center to the first and second electrons, and r is the distance of an electron from the center, hence

$$\frac{e^2}{r_{12}}+\frac{e^2}{r_{13}}+\cdots=\frac{1}{2r}\left(\frac{1}{\sin\delta_{12}}+\frac{1}{\sin\delta_{13}}+\frac{1}{\sin\delta_{14}}\cdots\right)$$
$$=\frac{1}{2r}S_n \qquad (7)$$

The work required to remove the electron is thus

$$\frac{Ec}{r}-\frac{1}{2}\frac{Ce^2}{r^2}-\frac{1}{2r}S_n \qquad (8)$$

but from the equation of equilibrium

$$\frac{Ec}{r^2}-\frac{e^2C}{r^3}=\frac{e^2S_n}{4r^2}; \qquad (9)$$

hence if V is the ionizing potential, Ve, since it is equal to the work required to remove the electron, is given by the equation

$$Ve=\frac{Ee}{2r}-\frac{3}{8}\frac{e^2S_n}{r}, \qquad (10)$$

if n is the number of electrons $E=ne$ and

$$V=\frac{e^2}{2r}\left(1-\frac{3}{4}S_n\right). \qquad (11)$$

Next take the case when the electron is removed so slowly that the system of electrons is always in equilibrium. The work required is the difference between the potential energy of the atom in its original state when it contains n electrons and in its final state when it contains $(n-1)$ electrons. The value of the former is

$$\frac{1}{2}\frac{ne^2}{r}\left(n-\frac{S_n}{4}\right) \qquad (12)$$

that of the latter

$$\frac{1}{2}\frac{(n-1)e^2}{r_1}\left(n-\frac{S_{n-1}}{4}\right) \qquad (13)$$

where r_1 is the radius of the atom when one electron has been removed.

For the equilibrium of the electrons in this state we have

$$\frac{Ee}{r_1^2}-\frac{e^2C}{r_1^3}=\frac{e^2S_{n-1}}{4r_1^2} \qquad (14)$$

from the equilibrium of the atom in its original state we have

$$\frac{Ee}{r^2}-\frac{e^2C}{r^3}=\frac{e^2S_n}{4r^2} \qquad (15)$$

hence

$$\frac{1}{r_1}=\frac{1}{r}-\frac{\left(1=\frac{S_{n-1}}{4n}\right)}{1-\frac{S_n}{4n}} \qquad (16)$$

and the difference between the potential energies is

$$\frac{1}{2}\frac{e^2}{r}\left\{n\left(n-\frac{S_n}{4}\right)-(n-1)\frac{\left(n-\frac{S_{n-1}}{4}\right)}{n-\frac{S_n}{4}}\right\} \quad (17)$$

$$=V_2e$$

if V_2 is the ionizing potential for slow ionization. In calculating these ionizing potentials we have assumed that the law of force between the positive charge and the electron was expressed by $\frac{Ee}{r^2}-\frac{e^2C}{r^3}$ at all distances. There is evidence, however, that the repulsive term varying inversely as the cube of the distance has only a limited range of action and that beyond this range the force varies strictly as the inverse square of the distance. If we suppose that the range of the repulsive force $\rho Ce/E$, then the work done in taking an electron from a distance r to an infinite distance will be

$$\int_r^{\infty}\frac{Ee}{r^2}dr-\int_r^{\rho Ce/E}\frac{e^2C}{r^3}dr$$

$$=\frac{Ee}{r}-\frac{1}{2}e^2\frac{C}{r^2}+\frac{1}{2}\frac{E^2}{\rho^2C} \quad (18)$$

In calculating the ionizing potential, we have neglected the last term and so have underestimated its value. Neglecting this correction, the ionizing potentials for the elements whose outer layers contain 1, 2, 3, 4, 5, 6, 7, 8 electrons, respectively, are given in Table V. r_1 is the radius of the outer layer of the one electron atom, r_2 that of the two electron atom and so on. The third column gives the potential in volts when the values of r_1 and r_2, given by W. L. Bragg (*loc. cit.*) are substituted in column 2. These values apply to the ionization of the atom and not of the molecule. In experiments on the ionizing potential it is the value for the molecule and not for the atom which is in general determined.

Specific Inductive Capacity

Further information about the atom is afforded by the study of the specific inductive capacity of the gas. We shall proceed to find the value of the specific inductive capacity of atoms containing different numbers of electrons.

The case of the one electron atom is exceptional because such an atom in its undisturbed state has a finite electrical moment; it will therefore tend to set in an electric field and this will give rise to a term in the specific inductive capacity independent of the displacement of the electrons inside the atom by the electric field; this term will vary rapidly with the temperature.[5] In addition to this effect due to the setting of the atoms there will be an effect due to the displacement of the electrons relative to the central core under the action of the electric field; this effect will be present in atoms containing more than one electron. The effect due to setting is absent when the normal atom has no finite electrical moment.

TABLE V

Number of Electrons in Outer Layer	Ionizing Potential for Quick Ionization	
1	$\frac{1}{2}\ e^2/r_1$	4.8 Lithium
2	$.625\ e^2/r_2$	8.1 Beryllium
3	$.633\ e^2/r_3$	
4	$.63\ e^2/r_4$	11.8 Carbon
5	$.54\ e^2/r_5$	12 Nitrogen
6	$.52\ e^2/r_6$	12 Oxygen
7	$.5\ e^2/r_7$	10.5 Fluorine
8		

Two Electron Atom

If a is the distance of either of the electrons from the center of the normal atom, X the external electric force, then if this force is in the direction of the line joining the electrons, the displacement δx of either of the electrons in the direction of the force is given by the equation

$$e\delta x=\frac{4}{5}a^3X \quad (19)$$

This displacement of the electron relative to the positive charge endows the atom with an electric moment $2e\delta x$, and if N is the number of atoms per cubic centimeter, the electric moment per cubic centimeter is

$$N\frac{8}{5}a^3X \quad (20)$$

hence if K_1 is the specific inductive capacity of these atoms

$$K_1-1=4\pi N\frac{8}{5}a^3 \quad (21)$$

If the electric force acts at right angles to the line joining the electrons, then

$$e\delta x=4a^3X \quad (22)$$

and K_2, the specific inductive capacity for

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[5] *Phil. Mag.*, *27*, p. 757.

atoms orientated this way, is given by the equation

$$K_2-1=4\pi N\times 8a^3 \qquad (23)$$

If the atoms in the gas are uniformly orientated, the specific inductive capacity K of the assemblage will be given by the equation

$$K=\frac{K_1+2\,K_2}{3}$$

or

$$K-1=4\pi Na^3\times\frac{8\times 11}{15} \qquad (24)$$

the refractivity of an element in the first period to the corresponding element in the second and third periods is the same for all the elements. We have seen that for members of the same family the ratio of the values of $K-1$ is equal to the ratio of the volumes of the elements. So from these experiments we arrive at the interesting deduction that, on passing from one period to the next, the volumes of all the atoms are increased in the same proportion.

TABLE VI

Specific Inductive Capacity of Atoms with Two to Eight Electrons

No. of Electrons	Arrangement	K	Mean Value of K
8 8	Cube Twisted cube force perpendicular to sq. face	$1+4\pi r^3 N.4'338$ $1+4\pi r^3 N.4'27$	$1+4\pi r^3 N.4'338$
7 7	One layer force perpendicular to plane of pentagon One layer force parallel to plane of pentagon	$1+4\pi Na^3.3'605$ $1+4\pi Na^3.4'634$	$1+4\pi a\ \ N.4'29$
6	One layer	$1+4\pi Nr^3.4'269$	$1+4\pi r^3 N.4'269$
5 5	One layer force perpendicular to plane of triangle One layer force parallel to plane of triangle	$1+4\pi a^3 N.4'655$ $1+4\pi a^3 N.4'027$	$1+4\pi a^3 N.4'236$
4	Tetrahedron	$1+4\pi Nr^3.3'9$	$1+4\pi Nr^3.3'9$
3 3	Triangle force perpendicular to plane of triangle Triangle force parallel to plane of triangle	$1+4\pi Nr^3.5'203$ $1+4\pi Nr^3.3'981$	$1+4\pi Nr^3.4'39$
2 2	Force perpendicular to line of electrons Force parallel to line of electrons	$1+4\pi Nr^3.8$ $1+4\pi Nr^3.1'6$	$1+4\pi Nr^3.5'87$

The value of the specific inductive capacities for gases whose atoms contain from two to eight electrons is given in Table VI, which has been calculated by Miss Woodward.

It will be noticed that if K is the specific inductive capacity of a gas in the atomic condition, K is equal to ga^3, where a is the distance of the outer electrons from the center of the atom, g is a quantity depending on the number of electrons in the outer layer. For elements belonging to the same family the number of electrons in the outer layer and therefore g is constant, so that the ratio of specific inductive capacities of two members of one family should be the same as the ratio of the volumes of the atoms. Cuthbertson has pointed out that there are some remarkably simple relations between the refractivities and therefore between the values of $K-1$, for consecutive elements in the same family. This is shown by Table VII given by Cuthbertson and Prideaux.[6]

Thus for these four families the ratio of

Some confirmation of this is furnished by the determinations by W. L. Bragg[7] of the diameters of the atom of the various elements, these were made by measuring by the Röntgen-ray method the distance between the metal and the negative element in a series of

TABLE VII

Element	Refractivities	Approximate Ratio
Helium	72.0	½
Neon	137.4	1
Argon	56.8	4
Krypton	85.0	6
Xenon	137.8	10
Fluorine	195	1
Chlorine	768	4
Bromine	1125	6
Iodine	1920	8
Nitrogen	297	1
Phosphorus	1197	4
Oxygen	270	1
Sulphur	1101	4

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[6] *Phil. Trans.*, A, *205*, p. 319.

[7] *Phil. Mag.*, *40*, p. 169.

salts. In these the atoms of the negative elements are probably negatively charged and are not in the state of neutral atoms. For the electronegative elements the diameters are as follows:

Å is 10^{-3} cm.
F = 1.35 Å O = 1.30 Å C = 1.54 Å
Cl = 2.10 Å S = 2.05 Å Si = 2.35 Å
Br = 2.38 Å Se = 2.35 Å
1 = 2.8 Å

For the ratio of the diameters, we have
Cl/F = 1.55 Br/F = 1.76 I/F = 2.07
S/O = 1.57 Se/O = 1.8
Si/C = 1.53

For these elements, which are all electronegative ones, there seems thus some evidence from direct measurements that the ratio of the diameters of the atoms of corresponding elements in two periods is constant. It does not, however, apply to the electropositive elements like the alkali metals. Thus, for example

Na/Li = 1.185 K/Li = 1.38 Rb/Li = 1.8
Mg/Be = 1.24 Ca/Be = 1.5 Sr/Be = 1.7 Ba/Be = 1.8

Thus the increase in the size of the atoms of corresponding metals in different periods is not nearly so large as in that of the atoms of corresponding electronegative elements.

(*To be continued*)

Radio Broadcast Central

WJY AND WJZ, NEW YORK CITY

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We feel fortunate at being able to present in the following pages so complete a description of the latest and undoubtedly the best equipped of broadcasting stations, termed "Broadcast Central" and operating under the call letters WJY and WJZ. This radio source of simultaneous classical and popular entertainment in reality functions as two independent stations in *each* of which there are sets of duplicate equipment, one being a reserve. In other words, the entire equipment would furnish the "makings" for four stations. Although it has been in service but a short time, and its duplex function an innovation, the operation of Broadcast Central has been phenomenally successful.—Editor.

On May 15th, this year, radio listeners in the eastern part of the United States were able to act as silent participants at the opening of the newest and latest broadcasting station situated at Aeolian Hall, New York City. The equipment at "Broadcast Central," as the new station has been termed, is operated by the Radio Corporation and embodies several new features to insure the highest quality of reproduction and continuity of service.

In the first place the location of Radio Broadcast Central is ideal in that it is at the heart of New York City, which is the center of some of America's best music and art. Excellent concerts and recitals are continually being held in Aeolian Hall itself and provision has been made to broadcast these programs. In addition, special wire lines run to the more important theaters and hotels so that outside programs are readily transmitted by the station.

Two-channel Operation

One of the chief features that is prominent at Broadcast Central is the "two-channel" operation or simultaneous transmission of two programs on separate wavelengths. One channel operates on a wavelength of 405 meters with the call letters WJY and is used to broadcast popular music, lectures, etc. It has been appropriately called the "jazz" channel. The second channel transmits on a wavelength of 455 meters and uses the call letters WJZ, replacing the station formerly located at Newark. The WJZ channel is used for the transmission of operatic and all classical music. Both studios are located on the sixth floor of the Aeolian building, while the transmitting equipment is housed in a special room built on the roof.

Description of Equipment

Studio

In describing the transmitting equipment it should be remembered that technically the two channels are identical, so that only one will be described. The apparatus comprising this equipment may be divided into three groups; viz., that contained in (1) the studio, (2) the control room, and (3) the transmitter room.

As may be seen in Figs. 1 and 2, each studio itself is a medium sized room which has been acoustically deadened by draperies and especially prepared walls to prevent objectionable echoes that might be picked up by the sensitive microphones.

Fig. 1. The Classical Studio, WJZ

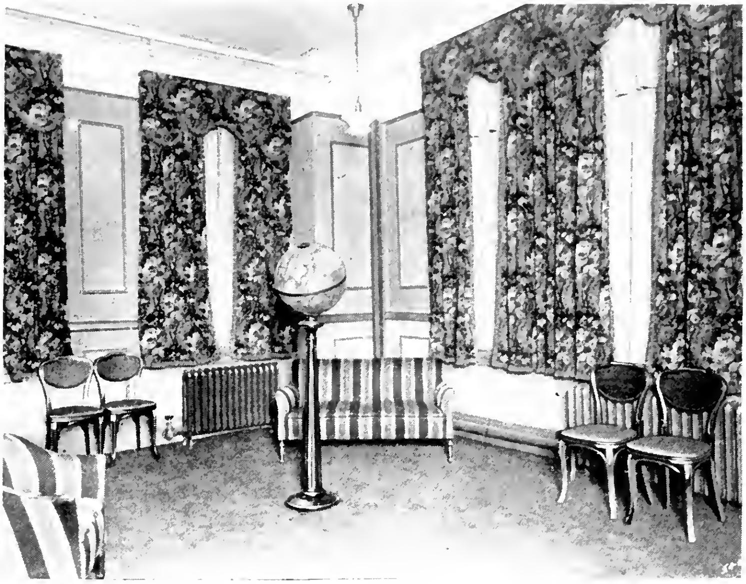

Fig. 2. The Popular Studio, WJY

The microphones used in "picking up" the music or speech of the various artists are two in number, and are mounted side by side on a portable pedestal which can be properly located with respect to the performers by the studio director. There are also two microphones on the announcer's desk, which are used only for making announcements regarding the program. Only one "announce" or one "concert" microphone is ordinarily used at a time; the control room operator having the power to choose which announce and which concert microphone shall be used.

The change from announce microphone to concert microphone is, however, at the disposal of the announcer or studio director by virtue of the "director's control box," Fig. 3, which is fastened to the desk near the announce microphone. This unit contains a three-way telephone key and a green-capped signal light. The three positions of the key are marked "Off," "Announce," and "Concert," and in each position the proper relays are operated in the control room to connect the tone generator, the announce microphone, or the concert microphone, respectively, to the amplifying equipment. This operation will be more fully described later.

The key is also utilized to operate a signal system which indicates whenever any transmission is taking place from the studio. Whenever the key is not in its "off" position, a contact is closed which lights two small red signal lamps, one of which is in the control room, and the other in the transmitter room. Also another contact is closed which, through a relay, effects the illumination of a red-lettered sign in the studio reading "Silent," and a similar sign in the reception room reading "Caution." Thus everyone connected with the transmission of the program is warned of the fact that the studio is in operation, and interruption is reduced to a minimum.

The green signal light in the studio control box is for the purpose of informing the studio director or announcer that the station is in operation and all apparatus in readiness for the program. The method for operating this signal will be described later.

Fig. 3. Director's Control Box

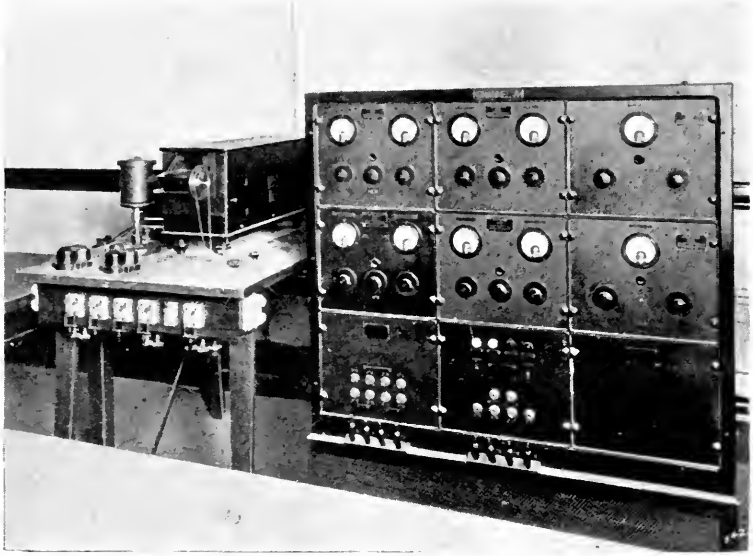

Fig. 4. Microphone Amplifier Rack

Control Room

Passing now to the control room, we have three main units: (1) the microphone amplifier rack, (2) the oscillograph, and (3) the time-signal receiver. The microphone amplifier rack is shown in Fig. 4. It is an angle-iron framework having nine sections, into which removable units of uniform size may be bolted. The units used in this rack are four "microphone amplifiers," two "line amplifiers," a microphone control panel, a filament control panel, and a chopper unit.

Each microphone amplifier contains the apparatus for controlling the current which will flow through any microphone connected to it, an amplifying tube (UV-202), microphone transformer for transferring the output of the microphone to the input of the amplifying tube, and a variable-resistance shunt across the primaries of the transformers whereby the volume obtained from the amplifier may be regulated.

The method of connecting the various microphones to the amplifiers provides maximum flexibility by means of the microphone control panel seen at the lower left-hand corner of the rack. On this panel are four telephone jacks, each one of which is connected to one of the four microphones situated in the studio. At the bottom of this panel hang four telephone plugs, each one being connected to the input of one of the four microphone amplifiers. Thus by properly manipulating these plugs, any microphone may be connected to whatever amplifier it is to operate. It should also be noted that there are several spare jacks on the panel to accommodate any additional microphones which may be installed.

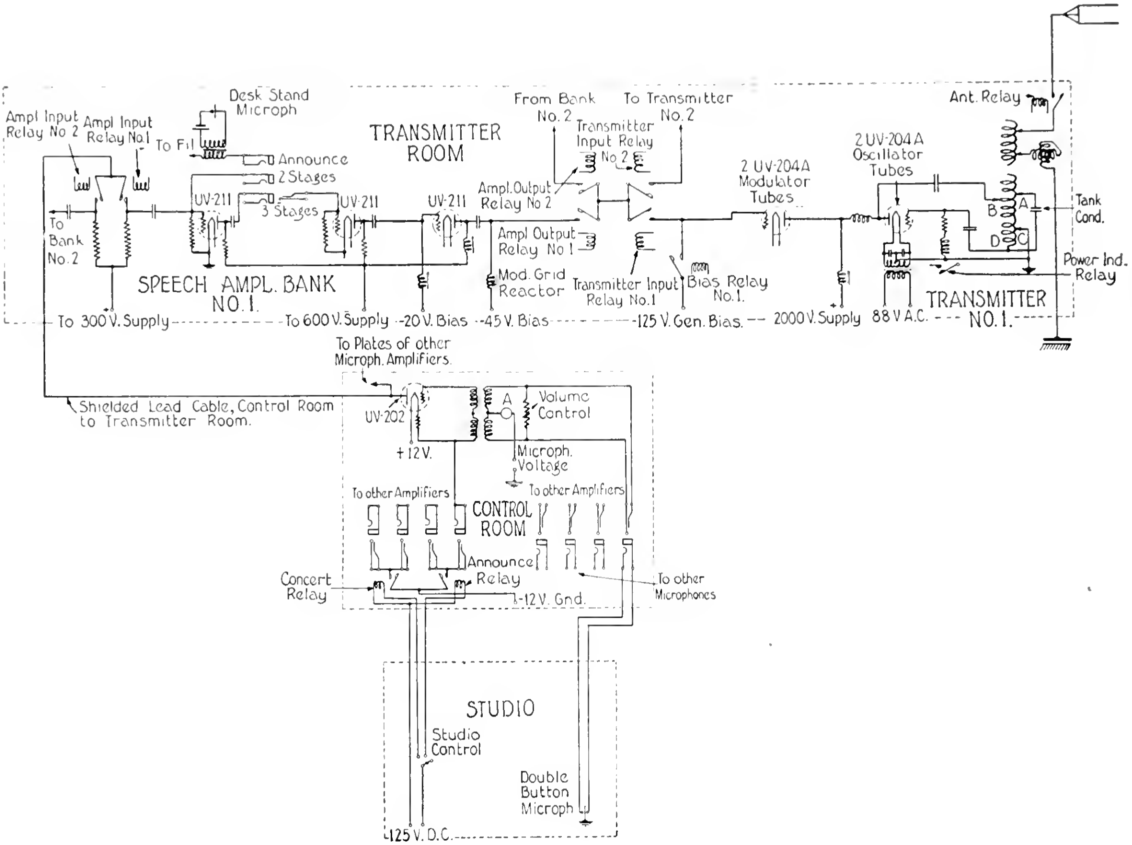

Fig. 5. Simplified Connection Diagram of One Channel at Broadcast Central

Having conducted our program in electrical form to the input of the first amplifier, we come next to the filament control panel whose function is to determine which of the four amplifiers shall be connected to the succeeding apparatus. The simplified schematic wiring diagram shown in Fig. 5 will assist in following the various amplifier circuits.

The first point to be noted is that the output of all the five-watt amplifiers (UV-202) is connected to a common wire which goes directly to the "speech amplifiers" located in the transmitter room. Thus the only operation necessary to place any one amplifier in operation is to light the filament of the respective amplifier tube. In the filament control panel are four telephone jacks each one of which forms one side of the filament circuit of one of the four amplifiers. Below the panel are two pairs of telephone plugs, each pair being connected to an individual relay which, when closed, will place filament potential on the plugs connected to it. These two relays are known as the "announce" and "concert" relays, and are operated by the corresponding position of the studio director's control key. To make clearer the functions of the various control units, we shall follow through the operations necessary for placing the microphone amplifiers in readiness for a concert.

The control room operator decides that he will use, for instance, announce microphone No. 1, and concert microphone No. 2. Also he decides that he will use microphone amplifier No. 1 for announce purposes, and amplifier No. 3 for concert purposes. First he goes to the microphone control panel and inserts the plug labeled "No. 1" into the jack "Announce No. 1," and also the plug "No. 3" into the jack "Concert No. 2." This connects announce microphone No. 1 which is on the studio director's table to the input of amplifier No. 1 and also connects concert microphone No. 2, which is on the microphone stand in the studio, to the input of amplifier No. 3. The operator adjusts the current in the two microphones and goes to the filament control panel. Here he inserts one of the plugs connected to the announce relay into jack "No. 1," and also one of the plugs connected to the concert relay into jack "No. 3." Now as soon as the studio director moves his key to the announce position, the announce relay is operated thereby lighting the filament in amplifier No. 1, and causing sounds picked up by announce microphone No. 1 to operate the set. Again, when the studio key is moved to the concert position, the announce relay drops out while the concert relay comes in, lighting the filament of amplifier No. 3 and placing concert microphone No. 2 in readiness for the artist or performer.

Another feature not previously mentioned is performed by the studio control key when in the "off" position. Two relays are operated simultaneously in the chopper unit, which unit contains, as suggested by its name, a chopper or tone-wheel driven by a small direct-current motor. One of the relays starts the motor and the other connects the brushes of the chopper wheel directly from the plate circuits of the microphone amplifiers, to ground. Since there are 16 insulated segments on the tone-wheel, which revolves at 1800 r.p.m., the effect of this device is to make and break current through the microphone amplifier plate resistance 480 times a second, thereby modulating the transmitter with a 480-cycle note. A variable resistance is shunted around the tone-wheel to control the amount of fluctuation of current and consequently the intensity of the tone produced. This arrangement was designed so that, if desired, the station could be given a distinguishing tone, enabling it to be easily tuned in when not actually broadcasting a selection. The tone may be easily eliminated by opening the motor supply.

The two line amplifiers are in the two upper compartments of the right-hand row, and consist of an amplifying tube (UV-202), a rheostat for controlling the intensity of amplification, and a transformer for coupling a telephone line or other source of signal to the input of the tube. Thus concerts or speeches from distant points can be transmitted over land line to the broadcasting station and then radiated in the usual manner.

Before leaving the microphone amplifier rack, mention should be made of a few other units to be found on the filament control panel. A jack labeled "Studio Output" is in series with the common output of the rack, thus enabling the operator to assure himself that his part of the apparatus is functioning properly. Also there is a jack labeled "Radio" which furnishes the operator with the output of a crystal receiving set for the purpose of observing the quality of the radio transmission.

Of the four signal lights seen at the top of the panel, one is the red signal previously mentioned, one a green signal in series with that of the studio control box, and the other two are white signal lights used for signalling between the control room and transmitter room.

In order to enable the operator to make the proper adjustments of the amplifiers, means must be provided for determining at all times how much the antenna current is being modulated. This is sometimes done merely by listening to the signal intensity with a receiving set, or by noting the fluctuation of current to the modulator tubes, or by measuring the voltage across the modulation reactor. These methods are, however, only comparative and approximate, and give little idea of the actual percentage of modulation. For these reasons an oscillograph is furnished in the control room. (This is the unit on the left in Fig. 4.) A rectified portion of the antenna current is supplied from the transmitter room by a vacuum-tube rectifier, to the vibrator of the oscillograph, thereby giving a continuous picture of the output of the station on a motor-driven mirror. The light for the oscillograph is furnished by a specially developed high-current incandescent lamp, supplied through a transformer from the 88-volt 30-cycle winding of an exciter in the transmitter room. Current for the mirror motor and magnetic field is supplied from the lighting mains at 115 volts direct current.

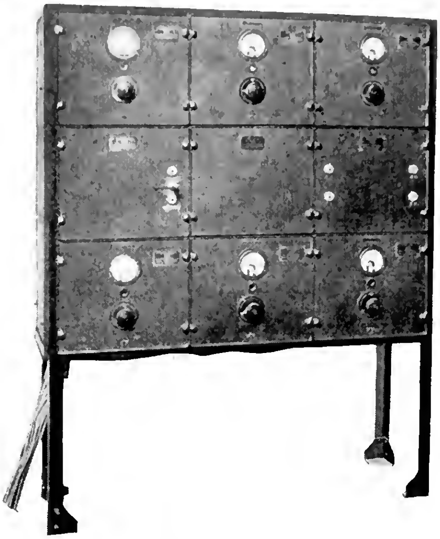

Fig. 6. Speech Amplifier Rack

The only remaining unit situated in the control room is the time-signal receiver. In order to transmit the naval observatory time signals, which are broadcast from station NAA at twelve o'clock noon and ten o'clock night on a wavelength of 2500 meters, means have been provided for re-radiating these signals at the normal broadcasting wave. For this purpose a receiving set is supplied which contains, in addition to the tuning, detector, and amplifier system necessary for picking up NAA's signals, a double-trap circuit which prevents energy from the WJZ and WJY antennas from being picked up and fed back into the input thereby causing howling. The output of this receiver is fed into one of the line amplifiers previously mentioned, and thus NAA's natural tone is again sent out in the same manner as a concert or speech from some outside source.

Transmitter Room

We shall now pass from the control room up to the transmitter room. This is in a special building erected on the roof of the Aeolian building, and situated midway between two 120-ft. structural-steel towers which are located at each end of the roof about 175 ft. apart. Within this building is housed all the power equipment of the station including motor-generator, batteries, speech amplifiers, and the transmitting units themselves.

Still following our entertainment as it passes through the various groups of apparatus, we come now to the speech amplifier rack. This unit, Fig. 6, follows in its mechanical construction the general form of the microphone amplifier rack in the control room as it also is divided into nine small compartments, each containing an individual unit. In this case, however, the whole lower row of units, consisting of two resistance-coupled amplifiers and a reactance-coupled power amplifier, is an exact duplicate of the upper row, while the middle row contains the coupling unit on the left, the input unit in the middle, and the output unit on the right.

In explaining the operation of this unit it will be remembered that the plates of all the amplifying tubes in the control room are connected to a common point. From this point a specially shielded line runs up to one contact of each of two relays in the coupling unit. Since these relays, called amplifier-input relays, merely determine which of the two duplicate rows of amplifiers the speech current will enter, we shall follow only the lower route. The other contact of the relay corresponding to the lower bank is connected to an 80,000-ohm resistor and also to a 0.5-microfarad condenser. These form a plate resistance and coupling condenser for the microphone-amplifier tubes below. Thus the output of the microphone amplifier is really the other terminal of the coupling condenser which goes directly to the input of the lower left-hand speech amplifier, and also to the sleeve side of a two-circuit telephone jack mounted in the coupling unit and marked "Two Stages." The speech amplifier just mentioned is, like the microphone amplifier, of the resistance-coupled type, but uses a 50-watt pliotron, 100,000-ohm grid leak, 40,000-ohm plate resistance, and 0.5-microfarad coupling condenser. The output of this amplifier is led back to the coupling unit and connected to the sleeve side of another telephone jack marked "Three Stages." The third jack shown is marked "Announce," and the sleeve side of this jack is connected to the secondary of a microphone transformer whose primary is connected to a desk-stand microphone on the operator's desk. So it is seen that the sleeve side of each of these jacks normally carries an audio-frequency voltage from an individual source. These voltages are utilized by means of a telephone plug whose sleeve side is connected to the input of a second speech amplifier which is an exact duplicate of the first, and occupies the center position in the lower row of units. The output of this unit is connected directly to the input of the unit immediately on its right, which is a reactance-coupled amplifier. Since this is the last stage of amplification before the modulator grids, it must handle considerable power with good regulation, for which purpose reactance instead of resistance is used in both the plate and grid circuits of the 50-watt tube. On account of the low ohmic resistance of the plate reactance, a negative bias of about 30 volts is fed through the grid reactance to prevent excessive plate current, and to provide linear amplification. The output from this last stage is obtained through a 0.5-microfarad coupling condenser as in the previous stages.

Now the purpose and marking of the three jacks in the coupling unit may be easily understood. If the plug carrying the input circuit of the second speech-amplifier stage is plugged into "Three Stages," all three stages are in operation in cascade. If it is plugged into "Two Stages," the output of the coupling unit, or microphone amplifier, passes directly to the second stage thereby eliminating the first resistance stage. If the plug is inserted in "Announce," the output of the operator's microphone is connected to the last two stages, and the transmitter may be modulated from the transmitter room independently of the studio.

On returning to the output of the reactance amplifier it should be noted that an exactly similar path may be traced through the upper row of amplifiers, using the tip connections of the telephone plug and jacks mentioned. Thus the output of the reactance amplifier passes through an amplifier-output relay to a bus common to four relays. These consist of the two amplifier-output relays and two transmitter-input relays whereby either set, or bank, of amplifiers may be connected to either transmitter as desired in a manner to be described later.

Grid bias for the modulator tubes is normally supplied by a 45-volt dry battery connected through a high reactance to the output of whichever reactance amplifier is being used. These reactors are located in the respective reactance stages themselves.

Fig. 7. Transmitting Panel

The four relays mentioned, together with two more known as biasing relays, make up the output unit. Jacks for listening to the outputs of the four resistance stages are also located on this panel.

The input unit contains only four relays for supplying plate and filament voltages to either one or both of the two amplifier banks.

Having passed through the speech amplifiers, we come now to the transmitter proper shown in Fig. 7. This unit utilizes two 250-watt oscillator tubes and two 250-watt modulator tubes (UV-201-A) supplied, by means of power relays, with 11 volts alternating current for filaments, and 2000 volts direct current for plates. The primary oscillating circuit is not conductively coupled to the antenna, but consists of an edgewise-wound copper strip inductance and a high-efficiency mica condenser. The Hartley oscillating circuit is used and movable clips on the inductance provide for adjusting the wavelength as well as the plate and grid voltages for best operation. Placed in inductive relation to this primary inductance is a similar inductance coil connected through an antenna relay to the antenna post of the transmitter. The low-potential end of the coil is connected through a variometer to the counterpoise terminal of the transmitter, which terminal becomes ground if no counterpoise is used. Adjustable taps on this coil, in conjunction with the variometer, allow the antenna to be tuned to the frequency of the primary or tank circuit, under which conditions maximum energy is supplied to the antenna from the tank. The advantage of this circuit is that, due to the relatively loose primary to secondary coupling and the fairly high circulating energy in the tank, slight changes in antenna constants caused by swinging do not appreciably change the radiating frequency. This is very essential for steady reception.

While considering the oscillating circuit, mention should be made of the operation of the green power-indicating signal lamps previously mentioned as being located in the control room and studio. Whenever the transmitter is oscillating properly, a current of from 30 to 60 milliamperes flows in the grid leak circuit. A portion of this energy is used to operate a small relay, which in turn lights the two green signal lamps in series. In order that this signal may not be lighted when the set is oscillating into the tank and not supplying energy to the antenna, a spare contact on the antenna relay is also included in the lamp circuit, allowing illumination only when the antenna is actually connected and radiating energy.

Fig. 8. Interior of the Transmitter Room

The modulation system used is the well-known plate system whereby the voice-frequency voltages impressed upon the modulator grids by the speech amplifier cause corresponding voice-frequency voltages of much greater intensity upon the oscillator plates, which changes of voltage in turn cause audio-frequency variations in the amplitude of the radio-frequency output. Thus the weak sound waves acting upon the microphone diaphragm in the studio are reproduced in form, with very little distortion, in the powerful variations of radiated energy emanating from the antenna system to be intercepted by thousands of radio receiving sets which reproduce more or less perfectly, the original sound waves.

Several more units accessory to the operation of this whole system remain to be described. The filter panel, Figs. 8 and 9, is situated between the two transmitters and contains two resistance and capacity filters which cut down and smooth the output of one commutator of each 2000-volt generator to supply the proper plate voltage to the microphone and speech-amplifier tubes. A separate filter is provided for the generator belonging to each of the two transmitters, and the two required voltages are supplied from the proper filter by two pairs of relays, known as filter relays, whose operation is described later. The filter panel is also used to mount the filament voltmeters and rheostats of the two transmitters.

The heart of the whole transmitter room apparatus is the operator's control box, Figs. 10 and 11. This unit contains all the various jacks, signals, and switches that are necessary for supervision and for operation of the various relays previously mentioned. Of the three signal lights seen at the top of the unit, two are white and one red, and each is in series with the corresponding lamp in the filament control panel in the control room.

Four telephone jacks are shown. The lower left-hand jack is labeled "Studio Output" and is in series with the corresponding jack in the filament control unit in the control room. The upper left-hand jack allows supervision of the input to the modulator tubes by means of a high series resistance connected to the modulator grid circuit of whichever transmitter is being used. The jack on the lower right gives an indication of the radio output of the channel by means of a simple crystal receiver. Thus complete supervision of operation may be had, step by step, throughout the equipment.

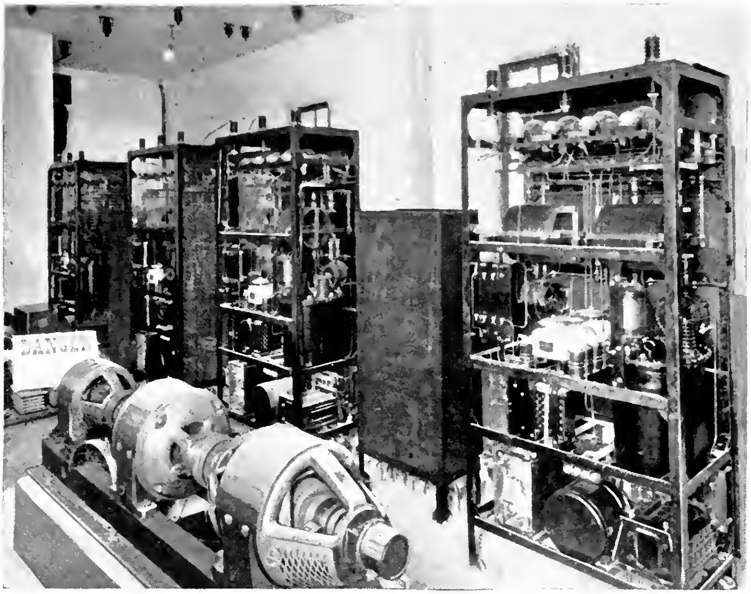

Fig. 9. Another View of the Interior of the Transmitter Room

The last jack shown is for plugging in the desk stand microphone for announcing or testing purposes, as has been described.

The top row of switches on the control unit is in connection with the transmitter alone. The push-button type on the left operates the automatic starter of the motor-generator set belonging to the left-hand transmitter. The right-hand push button belongs correspondingly to the right-hand transmitter. The center switch of this row is a single-pole double-throw tumbler switch. Thrown to the left, it operates the antenna relay and transmitter input relay of the left-hand set, and also the two filter relays cor-

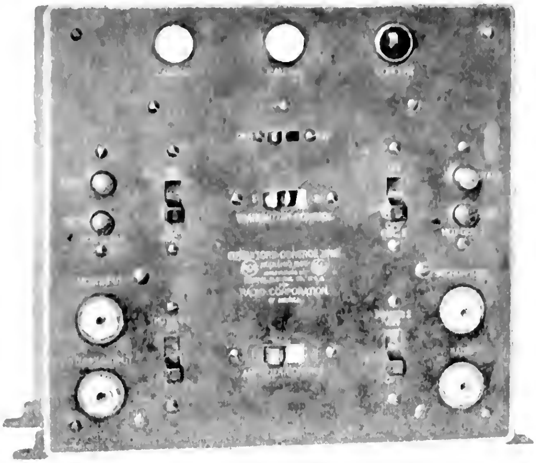

Fig. 10. Operator's Control Box

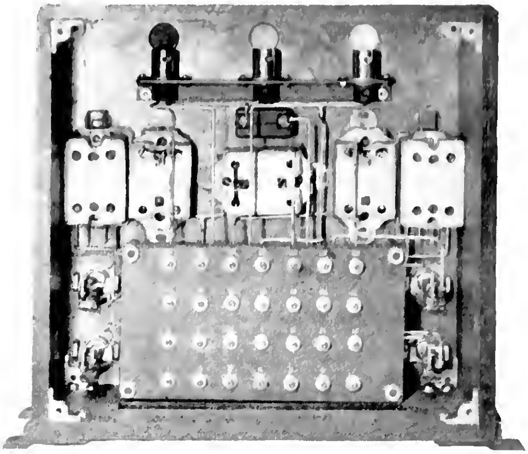

Fig. 11. Interior of Operator's Control Box

responding to the filter used with the left-hand generator. In this manner the left-hand set is connected to the antenna and to the amplifier output, and is ready for operation as soon as the high-voltage field relay and the filament lighting relay are closed. These latter operations are taken care of by the vertical single-pole single-throw tumbler switch on the left. Also that filter is connected in which it is sure to receive power from the generator in use. Throwing the middle switch to the right and throwing up the right-hand tumbler switch perform exactly the same operations for the right-hand transmitter.

Since power is supplied to a transmitter on the operation of the corresponding vertical switch alone, regardless of the position of the middle horizontal switch, it is seen that the set may be caused to oscillate into the tank circuit without feeding energy to the antenna. This is often desirable, but it is also evident that under these conditions the transmitter input relay for this set is open, hence the modulator grids do not receive their normal bias. This is taken care of by the bias relay which places negative 125 volts from the motor-generator on the modulator grids of the set not in actual operation.

The lower row of switches in the control box pertain to the amplifiers only. The two outside vertical tumbler switches are labeled "Power No. 1" and "Power No. 2" and operate the proper relays in the input unit to supply plate and filament current to the lower and upper banks of amplifiers respectively. The center horizontal tumbler switch, corresponding to the transmitter changeover

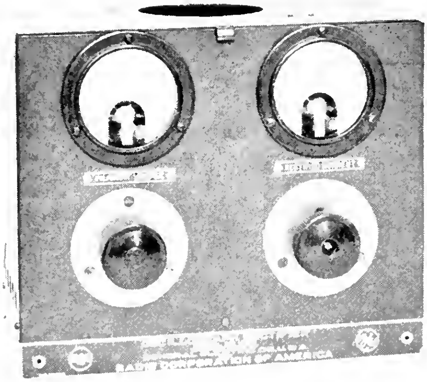

Fig. 12. Oscillograph Rectifier

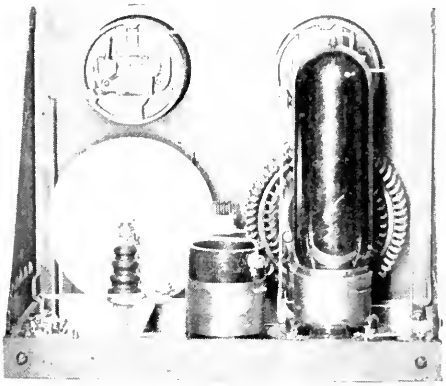

Fig. 13. Interior of Oscillograph Rectifier

switch above, places either one of the amplifier banks in circuit. Thus if thrown to the left, the amplifier input relay in the input unit belonging to the lower amplifier bank, and also the amplifier output relay in the output unit belonging to this same bank are closed. When thrown to the right, the corresponding relays for the upper bank are closed.

The extreme flexibility of the whole equipment may now be seen as there is a complete duplication throughout of every important part of apparatus necessary for the transmission of a program. Also, changeover from one piece of apparatus to another is made very easy and rapid by use of concentrated controls which operate remote relays.

A small though important piece of apparatus which is used in connection with the oscillograph is the oscillograph rectifier, Figs. 12 and 13. This unit is mounted on the wall of the transmitter room near the antenna lead-out. A small edgewise-wound inductance which is mounted in inductive relation to a single loop in the antenna lead is tuned by a variable condenser within the rectifier. A portion of the high-frequency current set up in this tuned circuit is sent through a rectifier tube (UV-217) and the resulting rectified current, whose pulsations are an exact copy of the audio-frequency variations in the radiated wave, is passed through the vibrator of the oscillograph in the control room below for visual observation of the final output of the whole equipment.

The three-unit motor-generator set used with the transmitters is shown in Fig. 14. The middle machine is the motor which operates on 125 volts direct current from the building main. The right-hand machine is a combined alternating current and direct current generator furnishing 125 volts direct current for the high-voltage generator field and grid bias, and 88 volts alternating current for filament lighting and the oscillograph lamp. A voltage regulator keeps the alternating-current voltage of this machine constant, thus insuring constant filament temperature when once adjusted The left-hand machine is the high-voltage generator which has a 1000-volt commutator at each end thus giving 1000 volts for the amplifier plate filter and 2000 volts for the transmitter.

Fig. 15. Roof of Aeolian Hall showing the Antennas

The only unit which is common to the two channels is the battery charging panel. Two 480-amp.-hr. 12-volt lead batteries are supplied with each channel for filament lighting and signalling. A single motor-generator is used for charging, and by a system of double-throw switches any of the four batteries may be placed on charge or discharge thereby providing absolute continuity of service if desired. The biasing batteries for the modulator tubes and reactance amplifiers are mounted in the rear of this panel.

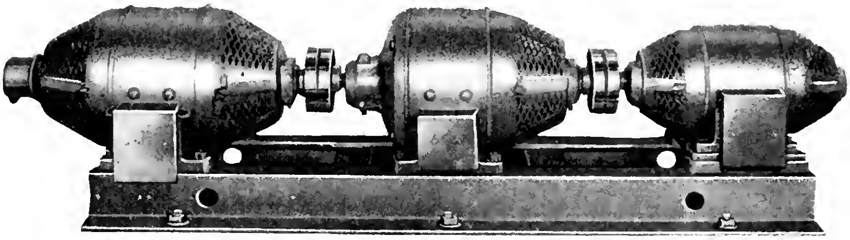

Fig. 14. Three-unit Motor-generator Set

In concluding the physical description of the installation, mention should be made of the antennas, or radiating system, which are shown in Fig. 15 and also on the cover of this issue. As already mentioned, two 120-ft. towers are located about 175 ft. apart on the roof with the transmitter room midway between them. Near the top of each tower is a cross arm 36 ft. long from which the four antenna wires are suspended. The total span between the two towers is broken up by ropes and insulators to form two separate four-wire antennas, one on each side of the transmitter room. The antenna on the 42nd Street side of the building is 55 ft. long, and a four-wire down lead descends from this to the two transmitters used for the classical channel which operates on 455 meters. The antenna on the 43rd Street side is 45 ft. long and a similar down-lead makes connection with the transmitters of the channel which operate on 405 meters.

Audio Amplifier Design

The microphones or "pick-up" devices used in broadcast work are designed to give, as nearly as possible, a uniform response for all frequencies in the audible range. This means that a range of approximately 30 to 5000 cycles must be covered. It also follows that the amplifier and associated circuits must cover this frequency range if high-quality transmission is to be obtained.

In order to modulate completely the output of one of the transmitters at Broadcast Central, the audio voltage applied to the oscillators must be about 2000 volts. The output of a high-quality microphone is very small due principally to the highly damped diaphragm and seldom exceeds a few millivolts. It is therefore evident that considerable amplification is necessary before the feeble output of the microphone can be effectively utilized.

The following equations give approximately the voltage amplification per stage that is obtained in the amplifying equipment.

The first stage or microphone amplifier uses a radiotron (UV-202) with 80,000 ohms resistance in the plate circuit, Fig. 5.

We may express the useful amplification factor of this type of resistance amplifier by

$$u' = \frac{u\,R_L}{R_p + R_L}$$

Where u' = useful voltage amplification.

u = amplification constant of tube.

R_L = external or series plate resistance.

R_p = internal plate-filament resistance of tube.

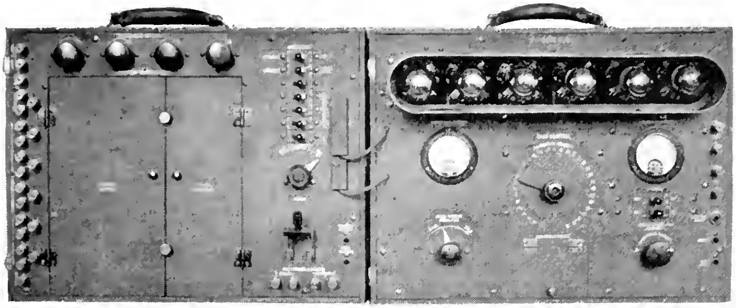

Fig. 16. Portable Control Equipment for Broadcasting from Outside Sources

Solving for u' in the case of tube employed we have

$$u' = \frac{7.5 \times 80{,}000}{7000 + 80{,}000} = 6.8 \text{ approx.}$$

In other words, the voltage developed across R_L and applied to the grid of the second stage is 6.8 times the voltage delivered by the microphone transformer secondary.

The second and third stage audio amplifiers are located in the transmitter room and use radiotrons of a different type (UV-211). The amplification constant of this type tube is 12 and a series plate resistance of 40,000 ohms is used. At the low-plate voltage available for this tube a plate resistance of about 5000 ohms is obtained.

Therefore u' for the second and third stages is

$$u' = \frac{12 \times 40{,}000}{5000 + 40{,}000} = 10 \text{ approx.}$$

The last stage amplifier also uses the same type and size of radiotron tube but is designed as a reactance amplifier since it must supply some power to the modulator grid circuit. The useful voltage amplification, n', as obtained in this last stage is nearly the theoretical value of 12 over the essential audio-frequency band.

Summing up, the total voltage amplification possible with all four stages is

$$6.8 \times 10 \times 10 \times 12 = 8160$$

In practice it is seldom necessary to use four stages, so that under average conditions the amplifier control plug on the speech amplifier bank is placed in the "Two Stages" position which disconnects one of the resistance amplifiers (UV-211).

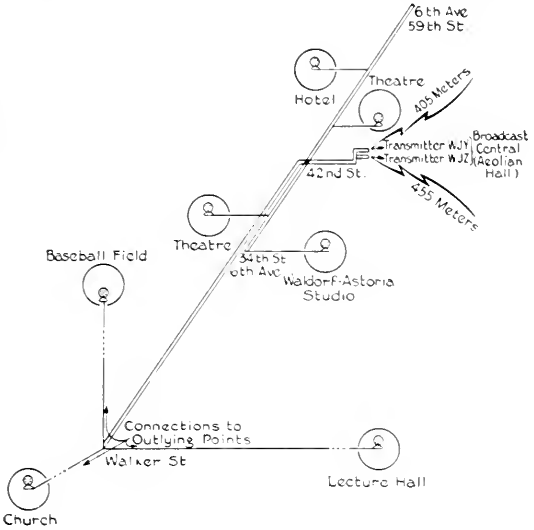

Fig. 17. Outside Private Cable System of Broadcast Central

Design of Radio Circuits

Two radiotrons (UV-204-A) are operated in parallel as power oscillators in each transmitter at Broadcast Central. Instead of using a direct coupled circuit as in many radio transmitters the tubes are connected to a primary or "tank" circuit which is in turn coupled to the antenna. This arrangement of the oscillators is shown in Fig. 5.

There are three important advantages gained by using a tank circuit coupled to the antenna.

1. The frequency of the oscillations is determined almost entirely by the constants of the tank circuit. Then should the antenna characteristics vary due to swinging, etc., the emitted frequency remains practically constant, making zero-beat reception more reliable for the distant listener.

2. Harmonic radiation is reduced to a negligible degree due to the selective properties of the coupled circuit.

3. With two-channel operation as carried out at Broadcast Central, reaction of one antenna on the other does not cause "cross talk." If power from one antenna enters the antenna system of the other channel the undesired frequency does not reach the tube circuits and consequently does not affect the modulation of that particular channel.

The following values represent a typical operating condition for one of the transmitters. Reference will be made to the oscillator circuit as shown in Fig. 5.

Wavelength 400 meters (750 kilocycles).
Antenna current 7 amp.
Antenna capacitance 0.0008 microfarad.
Tank current 9 amp.
Tank capacitance 0.0008 microfarad.

Under these conditions approximately 16 turns are required on the tank inductance. The alternating voltage required for the plate circuit of the oscillators is developed across turns B and C. The alternating grid voltage is determined by the drop across turns C and D. At 750 kilocycles, the 16 turns on the tank inductance have a reactance of about 265 ohms. This gives a reactive drop of 2385 volts with 9 amp. tank current. Assuming equal potential distribution across the used turns on the coil, the drop per turn is $\frac{2385}{16} = 149$ volts. Since 10 turns are used in the plate circuit between points B and C, the alternating plate voltage is 1490. Three grid turns are used between points C and D giving a resultant alternating grid voltage of 447. Due to the potential distribution not being uniform toward the lower end of the coil, the grid voltage is somewhat lower than this value.

The circulating kilovolt-amperes in the tank circuit may be expressed by $I^2 X$ where X represents the reactance of the tank capacitance or inductance at the operating frequency. In this case the tank kv-a. = $\frac{9^2 \times 265}{1000} = 21.46$. The antenna kv-a. may be expressed in the same manner and are equivalent to $\frac{7^2 \times 265}{1000} = 13$ approximately. It is therefore evident that the antenna kv-a. under these conditions are about 60 per cent of the tank kv-a. This ratio gives good stability and frequency holding characteristics. In general, the tank kv-a. must at least equal the antenna kv-a. for reliable operation.

Cooling of Turbine Generators

PART IV

UTILIZATION OF HEAT IN STEAM-ELECTRIC POWER PLANTS

By A. R. Smith

Construction Engineering Department, General Electric Company

This series of articles was started in our issue of December, 1922, when the author dealt in Part I with the various ways of cooling air when recirculated. Part II was published in our February issue and covered the heat transfer in surface air coolers, and in our May issue we published Part III which discussed the details of design. In this, the fourth and concluding article of the series, the author discusses the utilization of heat in steam-electric power houses, dealing in great detail with the heating of air for combustion and other features of heat utilization.—Editor.

The purpose of this article is to present the general problem of steam-electric power plant economies with respect to temperature exchanges in a manner which may be readily understood or even visualized. No radical departures from prevailing practices in modern plants are proposed except the heating of the furnace air as a means of still further improving the overall plant efficiency.

The common methods now employed for heating the boiler feed water may be classified as follows:

1. Fuel economizers.
2. Exhaust steam from steam-driven auxiliaries.
3. Extraction steam from the main turbine.

In some instances all of these methods may be used in series. The same means may be utilized for the heating of the air to the boiler furnaces with almost equal advantages. These, similarly classified, will be termed as follows:

1. Gas air pre-heaters (air economizers).
2. Steam air pre-heaters (using exhaust steam from steam-driven auxiliaries).
3. Steam air pre-heaters (using extraction steam from the main turbines).

The two major heat losses in a steam-electric power plant are in the gases leaving the stacks and in the circulating water leaving the condensers. It is obvious that if a relatively small percentage of this heat can be returned to the boilers or furnaces as a substitute for some of the fuel a gain will be effected. The problem, therefore, is to revert all of this heat possible to either the boiler or the furnace with the least complication and the highest efficiency. For many years there has been an intensive endeavor to reduce the temperature of the stack gases and to reduce the weight of the gas by proper combustion so as to minimize this loss. The waste of heat in the condensing water is far in excess of the stack loss and it is only recently that any concerted effort has been made to reduce this waste. It should be borne in mind that every pound of steam that can be kept out of the condenser should result in a thermal advantage, besides reducing the size of the condenser and the congestion of steam in the latter stages of the turbine which generally exists due to the rapid expansion of steam at high vacua.

Fuel Economizers

This name is not sufficiently descriptive because any piece of apparatus in the power plant which improves the efficiency is a "fuel economizer." A more proper name would be "waste gas water heater." Inasmuch as both the boiler and the economizer use the same gas (the economizer is now generally installed as a unit with the boiler) they should really be considered as a two-stage boiler because the only purpose of the economizer is to obtain a greater temperature difference between the gas and the water by dividing the unit into two stages so as to segregate the low temperature water from the water in the boiler which is at steaming temperature or thereabouts.

Possibly the greatest handicap to the economizer in the past was that the boiler manufacturer recommended and standardized boilers which took out so much heat from the gas that there was little work for the economizer to do, with the result that there were relatively few economizer installations and it was often difficult to justify the investment in economizers, except where the price of fuel was high and the load factor very good. The second handicap was that the installation of an economizer introduced considerable resistance to the flow of gas as well as lowering its temperature which generally necessitated the use of induced draft fans.

The operation of boilers at several times their rated capacities materially increases the draft loss and if induced draft fans are to be installed anyway, the addition of a fuel economizer is advantageous aside from the improved efficiency inasmuch as the fans can be reduced in size because of the higher pressure that must be produced and the smaller gas volume that is handled.

There is another possibility, and that is a reduction in draft loss through the boiler and through the economizer to such an extent as to make it possible to operate at high boiler ratings with reasonably high stacks and without induced draft fans. Excessive draft loss is largely the result of eddying, and simple baffles, properly arranged for more uniform gas velocities and as few turns as possible will undoubtedly greatly reduce the draft loss without affecting the performance.

With higher steam pressures, the water circulated in a boiler is of higher temperature and the use of fuel economizers becomes more and more advantageous. Furthermore, it is now more generally appreciated that with any predetermined exit gas temperature the division of heating surface between boiler and economizer should be carefully proportioned in order that each may do its proper share of the work.

There has prevailed amongst many operating engineers an impression that the feed water should not be heated by exhaust steam when fuel economizers are employed for the purpose of making a better showing for the economizer. This impression is wrong for the reason that the economic advantage of heating water with exhaust steam is then deliberately discarded for the sake of a different form of economy. Furthermore, from a practical standpoint it is essential to have the feed water enter the economizer at a temperature above the dew point of the gases to avoid sweating and the consequent accumulation of soot which can not be readily removed. The dew point of a gas will vary with the character of the fuel. There was an old rule that the water should be 120 deg. F., or higher, when coal was used and 140 deg. F., or higher, when oil was used. These limits are gradually being raised and some now recommend as high as 170 deg. F. for certain grades of coal.

It is obvious from the foregoing that the boiler feed water should first be heated by exhaust or extraction steam to a temperature higher than the dew point of the gases passing through the economizer for practical reasons and may be heated still hotter for economical reasons. The cost of equipment to heat water with exhaust or extraction steam is not so expensive as the equipment necessary to heat it with the flue gas. On the other hand, the temperature removed from the flue gas is a complete gain; whereas, the heat extracted from the low pressure steam is but a partial gain. Furthermore, the economic value of extraction steam becomes less as the temperature of the water increases because at the higher temperatures there is less work done by the steam in passing through the turbine. A balance must therefore be struck between the work that the economizer is to do and that which is to be done by the steam water heater. This division will vary materially for different steam pressures and different local considerations. However, there is a distinct field for gas heating and for steam heating of the feed water in every properly balanced power plant.

High Boilers

By the term "high boiler" is meant a boiler provided with more heating surface over which the gas travels so as to lower the flue gas temperature to a minimum. Such a boiler has a more uniform efficiency throughout its range of operation but when operated at its rated capacity may show but a slight improvement in economy over the standard boiler. The simplicity of a high boiler, if natural draft can be employed, as against the boiler with economizers and induced draft fans, will in many cases favor the former. As the steam pressure is increased, the load factor improved, and the cost of fuel raised, the economizer installation will then have the advantage. It is therefore apparent that there is also quite a distinct field of service for each of these two designs.

Exhaust Steam from Steam-driven Auxiliaries

This is by far the most common method of heating the feed water and besides its economic value, it served in the past to drop out some of the impurities in the water and minimized expansion and contraction stresses in the boiler. There existed, however, a somewhat prevalent idea that the efficiency or the water rate of such auxiliaries which exhausted into the feed water heater was of no moment. This is an erroneous impression because there is a definite amount of water which may be heated and there is a limiting temperature to which it may be heated, consequently there is a fixed amount of heat which may be utilized and the less efficient the auxiliaries, the fewer the number of auxiliaries which may be exhausted into the heater.

The necessity of using efficient auxiliaries or obtaining the most by-product power possible is now generally appreciated and the result is that most of the larger power plants are resorting to motor-driven auxiliaries and extracting the steam for heating the feed water from the main turbine where the lowest possible water rate per kilowatt may be obtained.

Extraction Steam from the Main Turbine

Aside from the simplicity, from both an installation and an operating standpoint, of electrically driven auxiliaries in a power plant, the plan of heating the feed water by extraction steam is conducive to a perfect heat balance and makes possible the production of the greatest number of by-product kilowatt-hours.

A kilowatt-hour produced as a by-product will have a fixed net steam consumption or net water rate regardless of the gross or apparent water rate because all of the steam exhausted from the machine is absorbed in the system as heat and therefore the net steam consumption is the heat in the kilowatt-hour plus the additional heat consumed in producing the mechanical and electrical losses of the machine; for example:

A kilowatt-hour contains 3412 B.t.u. If the machine has a mechanical and electrical efficiency of 90 per cent, then the total heat abstracted is 3750 B.t.u. which is equivalent to a net water rate of 3.87 lb. from and at 212 deg. If a turbine has a condensing water rate of 13 lb. from and at 212 deg., then the saving in pounds of steam per kilowatt-hour is 9.13 for every kilowatt-hour that can be produced as a by-product.

With a fixed amount of heat which may be absorbed by the feed water the greatest number of kilowatt-hours can be produced as a by-product by extracting steam from one of the latter stages where the lowest gross water rate prevails. But an extremely low gross water rate is accompanied by a low temperature, which naturally limits the amount of heat which may be put into the feed water. This condition is illustrated by the curves in Fig. 1, which show for a particular turbine that the greatest economy for single-stage extraction would be at the fourth stage, which is at a pressure of about 8 lb. gauge. This naturally will vary with different turbines, steam pressures, superheat, and other conditions.

The more economical method, of course, is to resort to series heating from different stages and the number of stages that should be employed depends so much on conditions that no general recommendations can be made. If the feed water were heated from each stage in succession, the resulting economy would be as shown by curve "BB" in Fig. 1. But the improvement over two- or three-stage heating would generally not be worth the complication and therefore the most economical condition, from an overall standpoint, would lie somewhere between curves "AA" and "BB."

Collection of Heat from Various Sources

The most natural thing to do is to collect unavoidable heat wastes in a plant such as: transformer losses, bearing losses, generator losses, drips, etc. The heat of the generator losses has in the past been wasted, except for a few isolated cases where this air has been discharged to the boiler room for combustion purposes and in many plants where the warm air was used in winter to assist in the heating of the turbine room. By using surface coolers for the generators it is possible to utilize most of the heat of the generator losses by circulating the condensate through the coolers. While the generator losses are a considerable factor when expressed as kilowatts, when converted into heat they are not of great magnitude and if the boiler feed water is heated by this means it must necessarily replace an equivalent amount of heating by extraction steam which is also an efficient process. Therefore, the absorption of the generator losses as heat can not be credited on an energy basis, but must be credited on a heat basis; comparing it with the saving in extraction steam to do the same work. The absorption of this heat, however, back into the system is often an important factor because otherwise it is a complete loss.

Heating of Air for Combustion

It is difficult to understand why we have always considered it economical and advisable to heat the feed water before it was fed to a boiler but never considered it advisable to heat the air fed to a furnace. Only in the last two or three years has this subject been given any particular attention, although pre-heating of air for combustion purposes has been used for many years in marine work in the form of the "Howden System" The amount of by-product electric energy which may be produced by heating the combustion air is almost as great as can be produced by heating the feed water, and the same statements can be made with reference to the reduction of the flue gas temperature by means of gas air pre-heaters as for gas water heaters or fuel economizers. Many engineers are still skeptical as to the resultant efficiency and fear that some difficulties may be encountered by introducing hot air, particularly with the stokers. Such disadvantages as have been suggested are discussed in the following paragraphs.

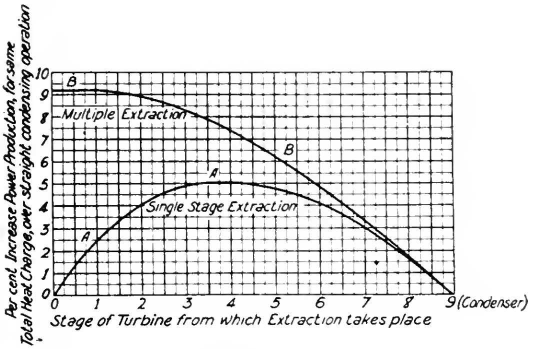

Fig. 1. Curves showing the Relative Economy of Single-stage Extraction and Multiple Extraction in Turbine Operation

Heat from Boiler Room

In the boiler room of small plants sufficient air for combustion can be taken from the building and this air may be relatively warm. In some cases it has helped to ventilate the boiler room; in others, it has produced air stagnation and was found objectionable. In the larger and more modern boiler rooms the amount of air used for combustion is so great that if it is not taken from outside the boiler room it is uncomfortably cold in winter and pipes are often frozen. Every provision is made for bringing fuel into a plant, but sufficient care is not always exercised in providing for the air. Fifteen to eighteen pounds of air is usually burned per pound of coal, which means that there must be delivered to the furnaces 200 to 250 cu. ft. of air for every pound of coal that is consumed. This most properly should be provided from outside the building and the ventilation of the boiler room can better be taken care of independently. Arrangements may be made whereby air for combustion is taken partly from the boiler room to assist ventilation but the great bulk of it must be figured at the prevailing outside temperatures.

Efficiency of Pre-heating Combustion Air

If the combustion of coal is thought of in terms of "burning air" rather than "burning coal," the process is simple to understand, and it is just as proper to talk of burning air or oxygen as of burning coal because there is used fifteen to eighteen times as much air as coal by weight. Aside from the radiant heat which is transmitted directly from the incandescent fire to the boiler heating surface, the great bulk of the heat produced by the union of the carbon and the oxygen is transmitted to the nitrogen and thence to the heating surface. In other words, the intense heat which would have been formed in the combination of CO_2 is diluted by the presence of nitrogen and the furnace gases kept within limits which may be handled with available materials. On one side of the stoker the air for combustion is delivered at a temperature ranging from 0 deg. F. to 90 deg. F. In the combustion chamber the temperatures may range from 2000 deg. to 2800 deg. F. If the combustion air enters the stoker at a higher temperature, then there is so much less coal that must be burned to increase the total gas temperature to the same point. On the other hand, if the amount of coal is reduced, then likewise the amount of air must be reduced so as to hold the same percentage CO_2 in the gases. Therefore, if the boiler is to do the same work with less coal and less air, the furnace temperature must be slightly hotter.

If it is conceded that the furnace temperature is slightly hotter and that the ratio of air to coal has not been increased then the stack losses remain unchanged and all of the heat that was put in the combustion air must represent a true gain and does not have to be multiplied by the boiler and furnace efficiency to obtain the net gain.

Increase in Furnace Temperature

At the present time furnaces are being worked to a temperature almost to the limit of the deformation temperature of the refractory materials and in many cases beyond the fusing temperature of the ash, and the general opinion is that if the furnace temperature is raised, the maintenance of the furnace might become excessive. This is largely a matter of speculation because it is a question if a high furnace maintenance is not due more to the radiant heat than it is to the temperature of the gases. It therefore remains to be seen if there would be any increase in furnace maintenance due to the employment of hot combustion air within reasonable limits. Furnace maintenance is very much aggravated when boilers are forced beyond their ratings. With a fixed amount of heating surface and a fixed quantity of heat to be applied to the combustion air the air temperature will be lower as the boiler rating is increased. Also refractory materials are being made to withstand higher temperatures than formerly and it is possible that more improvements will be made in the future.

However, if it is found that an increase in the temperature of combustion air shows an increase in furnace maintenance it is possible to allow a slightly higher ratio of air to coal and thereby reduce the CO_2 percentage in the gas and still show an improvement in efficiency, depending on how much the ratio of air to coal has been changed. On the other hand, some plants are working with a CO_2 percentage so high that at times some CO is produced which loss may more than offset the gain of the high CO_2. If the combustion air is heated and the CO_2 percentage lowered slightly, the operation is getting away from the danger line of the production of CO, and an improvement in economy may be effected in this manner alone. A number of plants are now being designed to use heated combustion air in some form or another and the results obtained will probably be available shortly.

Effect of Hot Air on Stokers

While most stokers depend on the cold air to hold down the temperature of the metal parts, the general opinion is that hot combustion air will not be detrimental to stokers, at least up to temperatures of 250 or 300 deg. F.

Warm Combustion Air for other Fuels

What has been said in connection with burning of coal applies equally well to other fuels, such as fuel oil, gas, and pulverized coal. With such fuels warm combustion air will undoubtedly improve combustion and may possibly permit the use of smaller combustion chambers. For liquid, gaseous and pulverized fuels warm combustion air has already been employed by passing it through or around the hot furnace walls with good success.

Gas Air Pre-heaters

The combustion air may be heated from the waste gases from the boiler or even from the fuel economizer. This construction has been used in Europe and is being contemplated in a few cases in this country. The gas air preheater has some advantages, when compared with the fuel economizer.

First: There are no high pressures to be dealt with and therefore thin steel tubes or plates or other forms may be used and need not be replaced until they are literally worn out.

Second: While the heat has to be transmitted from a gas to a surface and then from a surface to the air the unit heat transfer per square foot per degree difference is not materially different from a fuel economizer and the cost per square foot of surface should be considerably cheaper.

The gas air pre-heater also has some disadvantages, in that it is not always convenient to pass the air, which enters the stoker at the bottom of the boiler, by the gas which usually leaves at the top of the boiler. These two gases must be brought together some way and this introduces a limitation in the design of the boiler room. The gas air pre-heater is also subject to corrosion on the gas side, the same as a fuel economizer, and must take air at a temperature just as hot as the fuel economizer must take the water. Otherwise, the soot deposit at the cold end will make operation impracticable.

Steam Air Pre-heaters using Exhaust Steam from Auxiliaries

Inasmuch as a gas air pre-heater should accept air at a temperature in excess of 150 deg. F. to avoid sweating, then the air must be pre-heated by means of steam in the same manner as the pre-heating of water to an economizer. In winter if this air is at 0 deg. F., there is 150 deg. which must be put into the air. It is therefore essential that some form of steam air pre-heater be provided and this device can be made very simple, compact, and relatively inexpensive because the problems met with are comparatively easy. In the first place the resistance to the flow of heat on the steam side is very low, the steam being the best conductor in transmitting heat from it to a surface. On the air side there is no soot or dirt problem aside from the ordinary dust and impurities in the atmosphere which should go right on through the ordinary steam air pre-heater. Inasmuch as the air is being heated and not cooled, there is no dew point to be considered and therefore no tendency for the dirt entrained with the air to become moist and adhere to the heating surfaces.

These desirable conditions permit the use of finned tubes similar to those used for generator air coolers.

In a plant using steam-driven auxiliaries and where the heat balance is imperfect as is the case in most plants, any excess steam may be readily absorbed without complication to operation by introducing steam air pre-heaters.

Steam Air Pre-heaters using Extraction Steam

As the tide is rapidly changing from separately driven steam auxiliaries to motor-driven auxiliaries and the heating of the feed water accomplished by extraction steam, so the heating of the combustion air should be accomplished by extraction steam. Furthermore, the air can best be heated in stages in a manner similar to the heating of the feed water. This stage heating would be counter-flow and the low temperature of the air usually dealt with permits using steam from the latter stages of the turbine where the gross water rate would be lowest.

If steam is extracted from a turbine for heating the feed water to the maximum temperature practical and also for heating the air to the maximum temperature practicable, then the flow of steam to the condenser is reduced to a minimum and the same turbine should show a greater improvement for a high vacuum condition than if operating straight condensing. Also the same condenser should show a better vacuum with the same water temperature because of the reduced steam flow or a smaller condenser may be used to accomplish the same result.

Physical Consideration of Surface Heaters

In the past it was found to be cumbersome to heat the air because of the large amount of heating surface required. With the finned tube heater as used for generator coolers, the space occupied is very small. Such heaters can be installed in existing air ducts in many plants because the frontal area of a heater need be equivalent to a duct area having a maximum air velocity of 1000 ft. a minute. If the duct area is such that the maximum air velocity is 2000 ft. a minute it must be opened up only to double the area. The depth of the heater may be from 15 to 25 inches, depending on the amount of surface required.

The heating sections connected to a stage on the main turbine which operates at a pressure below atmosphere can be drained by means of vacuum traps and a vacuum pump, in a manner similar to any vacuum heating system in a building. This equipment is relatively inexpensive and simple to operate. The section using steam from a turbine stage at a pressure above atmosphere can be dripped back through traps to any receiving tank.

The installation of a surface air heater does not alter the design of the plant to any extent. It does not determine how the gases shall be taken away from the boilers, nor whether economizers should or should not be installed.

Operation of Steam Air Heaters

The steam air heaters can be paralleled with the water heater. The temperature of the air leaving the heaters will float with the temperature corresponding to the pressure in the particular stage of the turbine at any load. No regulation is necessary. If the steam is shut off from a heater section the air goes to the boiler cold, no harm resulting. If the air is shut off from a heater section the steam will not condense and there will be no flow from the main turbine. Thus, it will be seen that the regulation is inherently automatic.

The Development of Current Limiting Reactors and Their Shunting Resistors

By F. H. Kierstead

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The wisdom of using current-limiting reactors seems to be well recognized. The author lays much emphasis on the value of shunted resistance as a means of dampening out disturbances. This contribution has been written in the light of much experience and should give some of our operating friends useful data.—Editor.

In the early days of alternating-current generation and distribution, one of the difficult problems for the designer of apparatus was to reduce the reactance to a minimum. This practice continued until the size of generators had so increased that the short-circuit current of a generator, with the accompanying magnetic forces, was so great as to distort the armature coils, resulting in a general failure of the generator. It was therefore necessary to add external reactance to the generator circuits, in the form of current limiting reactors, in order to limit the current during short circuits and thus prevent the self-destruction of generators. This was only a transition period, however, and for a number of years generators have been built with sufficient internal reactance to enable them to withstand short circuit without injury. This transitory use of reactors for the protection of generators was the forerunner of a permanent demand for current limiting reactors in bus and feeder circuits.

As the use of electricity grew, more generators were connected to the same busbar and consequently the energy that flowed into a short circuit on the busbars or connected feeders was enormous. As a result, great injury was done to the circuits by the large magnetic forces, and the very rapid rise in temperature. Furthermore, the duty required of the circuit breakers in interrupting the current was beyond their capacity. It therefore has become necessary, in large systems, to separate the busbars into two or more sections connected together through reactors, in order to limit the flow of current to a value that the circuit can safely stand and the switches will interrupt. This practice of sectionalizing busbars with reactors is a permanent one which, it is believed, will grow in proportion to the growth in capacity of generating stations. The basis for this expected growth lies in the fact that it is not economical to increase the reactance of each generator connected to the busbars sufficiently to protect the bus circuit and switches.

Bus reactors give sufficient protection to small stations, but they by no means solve the problem of short circuits in big systems where the kv-a. capacity per section is large. This problem is three-fold. First, a short circuit on a feeder connected to a system protected with bus reactors alone results in very high temperature rises and great magnetic forces. Second, very expensive feeder switches are required to open the circuit. Third, the bus section voltage drops to zero, and the generators fall out of step. The complete solution of the problem therefore requires the use of reactors in the feeders which, in the case of a short circuit on a feeder, reduce the current that flows and enable the bus section voltage to be maintained at a high percentage of normal value. The dangers due to high temperatures and great forces are thus eliminated, less expensive switches are required, and the generators remain in step.

In large cities where two or more generating stations are tied together by lines operating at the generated voltage, it is necessary to insert reactors in the connecting lines which perform the same function as bus reactors. Of course in those cases in which the stations are tied together by lines operating at different voltages from the generated voltage, the transformers insert sufficient reactance for safe operation and reactors are not required.

The first reactors were used in 1911 as generator reactors, and then to a large extent in the nature of an experiment, but today they are as much a part of a modern station equipment as the switches themselves. Fig. 1 shows a typical outdoor installation.

In past years when the systems were small the capacity of a station was doubled without consideration of its effect upon the short-circuit current, but now no operator will increase his capacity 25 per cent without a careful consideration of its effect upon the operation of the station under short-circuit conditions. Today the control of short-circuit currents by current limiting reactors is a fundamental consideration in the equipment of a power station.

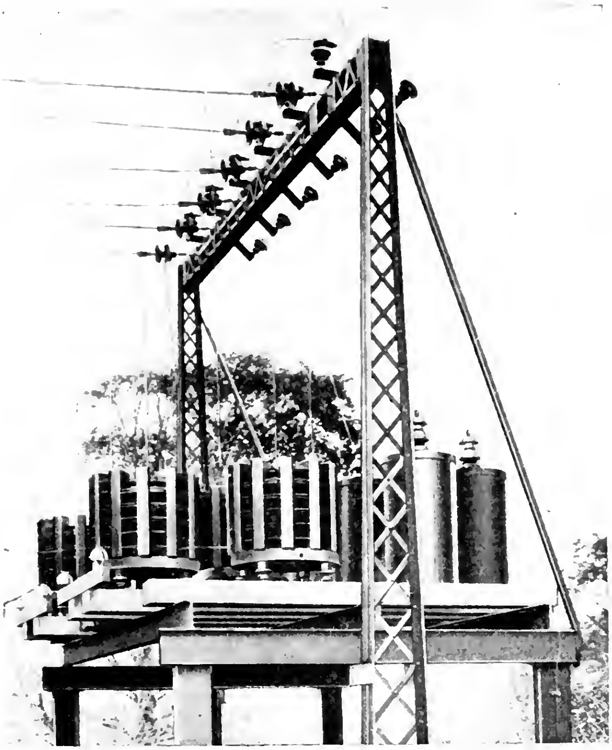

Fig. 1. A Typical Outdoor Installation of Reactors

The long experience in the manufacture and operation of reactors has cleared away the difficulties in their design. In the early days the designer did not know the magnitude of the magnetic forces within a reactor, and had only a hazy idea of their direction. Now their magnitude and direction are accurately calculated. Eddy losses also caused the designer considerable concern in those early days, for the reason that reactors were then built in which the total losses were three times the I^2R loss. In modern reactors the total losses are very little more than the I^2R loss. The next really serious problem that the designer had to solve was the magnitude of voltage across the reactor and the distribution of this voltage between its turns and layers. The voltage across the reactor under simple short circuits was easily calculated, but the real problem to determine was how high transient voltages might rise. There were good reasons to believe that they might be very high, and very high factors of safety were used in the insulation of reactors. In spite of this, some reactors in large stations failed in operation in a manner which seemed to indicate that the voltage stresses on the reactor were higher than had been anticipated.

About this time, the General Electric Company put into operation at the Schenectady Works a large generator of approximately 27,000 kv-a. continuous capacity and capable of developing nearly 300,000 kv-a. instantaneously. With this generator we made short circuit tests on reactors which proved beyond doubt that most of the failures, which we had heretofore attributed to high voltages, had been due to high magnetic forces. This proved to be a great advance in the art, as it cleared away the apprehension of high voltages and gave very definite data on the magnitude of the short-circuit forces. We are now able to calculate accurately the magnetic force on the weakest portion of the conductor and to determine the strength of that portion of the conductor so that we know the factor of safety we are using.

The past twelve years of experience in the design of reactors has led to the belief that aside from the case of a direct lightning stroke, voltages on a system seldom reach a value capable of causing a flashover of our reactors.

Operators have frequently been apprehensive that a short circuit on their system will be maintained for a long enough time to raise the temperature of the reactor so high that it will either fail at that time or will be so badly damaged that it will fail during the next short circuit. This very point was the determining influence in the adoption of the present fireproof reactor. Large currents have been held in these concrete reactors until the conductor melted and it was found that the reactor continued to operate up to the melting point of the conductor which leads to the conclusion that these reactors will operate satisfactorily during short-circuit periods up to the melting point of the conductor. On the other hand, the General Electric Company's fixed policy of conservatism has been maintained and reactors are guaranteed for temperatures at short circuit up to 350 deg. C. only. In all the years of manufacture of these reactors no failures due to overheating, caused by long continued short-circuit currents, have ever been brought to notice, and this experience indicates that the apprehension of operators on this score is not justified. On the other hand, up to a certain limit the net cost of a reactor with a large conductor is not so much more than one of small conductor, for the reason that the saving in the operation cost due to the reduced losses partially compensates for the increased cost of investment. For instance, if for an increased price which would entail an increased investment cost (including depreciation) of $50.00, a saving in operation cost due to the reduced losses of $50.00 is made, it would, by all means, be the better policy to buy the higher priced reactors, and gain the additional advantage of reduced temperature rise under short circuit.

Almost from the start of the electrical industry, engineers have recognized the important part that the resistance of a circuit plays in the limitation and reduction of transient voltages. The word resistance is used here broadly to include both the series resistance and shunting resistance of a circuit. Every transient is damped out solely by the energy absorbed due to the resistance of the circuit. If a circuit could be made without resistance, over-voltages would not be transitory, but would be permanent. The great advantage in having over-voltages die out rapidly is, of course, apparent and the first thought from the standpoint of protection is to increase the energy absorbed in the circuit so as to increase the rapidity with which over-voltages die away. On the other hand the efficient use of electricity requires the reduction of losses to a minimum. The problem, therefore, is to find a means of absorbing the destructive energy due to a disturbance without absorbing the useful energy that is being generated. A resistor shunting a reactor has this property. During the normal operation of the system, the voltage across the reactor and therefore across the resistor (since it shunts the reactor) is only a few per cent of the circuit voltage; and the energy absorbed by the resistor, which varies directly as the square of the voltage, is small. On the other hand, high-voltage disturbances generally occur at high frequencies and, because the frequency is high, the voltage built up across the reactor, and therefore across the resistor, is high. The energy thus absorbed, which is destructive in its nature, is large. Thus we see that resistors which shunt reactors are

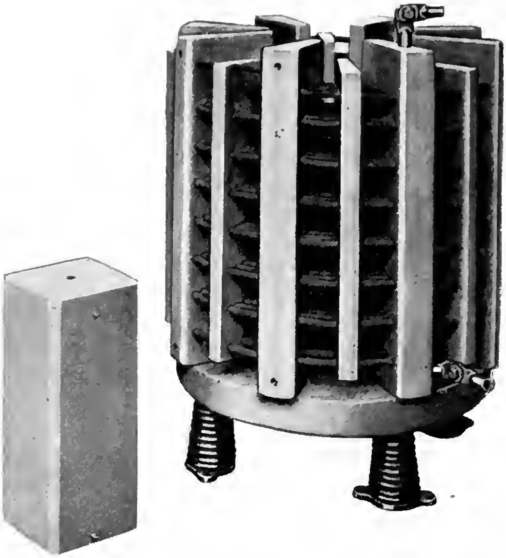

Fig. 2. Current-limiting Reactor with Shunt Resistor Placed Side by Side

selective in their operation, absorbing large quantities of dangerous energy and very little useful energy. The General Electric Company were early to realize the great protection from high voltages afforded by resistors shunting reactors and purchased the Campos Patents which cover the use of resistors shunting reactors for this purpose. Figs. 2 and 3 illustrate the standard construction of this type.

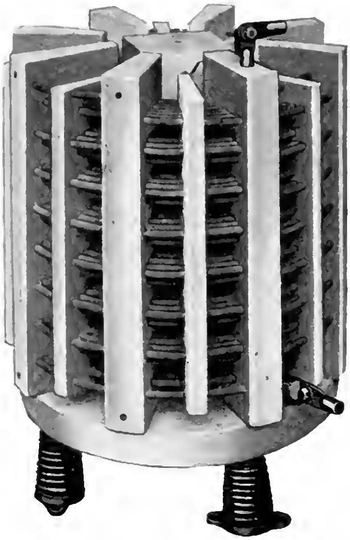

Fig. 3. Current-limiting Reactor with Shunt Resistor Assembled in the Proper Position

In modern power stations in which all the feeders which radiate from the busbars are equipped with current limiting reactors any steep wave front disturbance which originates in the station due to switching, etc., is trapped in the station by the reactors and therefore expends its energy in raising the busbar voltage instead of dissipating itself into the feeders which it would do if it were not for the feeder reactors. On the other hand any steep wave front disturbance coming in towards the station from one of the feeders, strikes the reactor and is reflected into the line where it dissipates itself.

If then each reactor is shunted by a resistor of high resistance compared with the surge impedance of the feeder, a steep wave front disturbance coming in from the feeder will still be largely reflected into the line and that which passes through will be largely absorbed by the resistor, while a disturbance originating inside the station will find a comparatively free passage, through the many resistors shunting the reactors, out into the feeders where it is dissipated.

In every power station there are combinations of inductance and capacity in series which may cause an increase in voltage due to resonance if comparatively low voltages having the proper frequency are impressed across them. There are also points in these stations corresponding to each of these combinations of capacity and inductance at which, if a short circuit or a switching operation occurs, oscillations will result at a frequency which will resonate with its corresponding combinations. While such potential dangers of high resonant voltages exist, the circuits of a modern system are so complex, that such resonating combinations are not recognized and cannot be eliminated. Such rises in voltage, however, will not be high if the damping is great, that is, if the energy absorption is great. The most effective manner of increasing the damping of these oscillations without increasing the losses, under normal conditions, is to shunt each reactor in the station with a resistor.

Summarizing, it has been shown that resistors which shunt reactors protect a system in two ways. First, by their unidirectional action of by-passing disturbances originating inside the station, but reflecting disturbances coming in towards the station, from a line. Second, by absorbing high-frequency energy and thus increasing the rate of damping-out of such disturbances.

In an article published in the July, 1921, issue of the GENERAL ELECTRIC REVIEW, by Messrs. G. Faccioli and H. G. Brinton, the authors have reviewed the action of the reactor shunted by a resistor and have shown the properties of such an energy absorber for minimizing the danger of high-frequency oscillations.

In the 1921 report of the Electrical Apparatus Committee of the National Electric Light Association, Dr. Charles P. Steinmetz and Messrs. G. Faccioli and F. W. Peek have very clearly stated why resistors shunting reactors are desirable.

The European practice has been for some time to shunt reactors with resistors. Professor W. Peterson of Darmstadt, the well known inventor of the Peterson grounding choke coil, has written a paper for the *Elektrotechnische Zeitschrift*, published February 20, 1913, in which he very strongly advises the shunting of all reactors with resistors.

It has been very difficult to obtain actual tests on a system with and without the reactors shunted by resistors under conditions such that high voltage should appear, due to the natural unwillingness of managers of electric systems to subject their plants to the hazards of a breakdown during the tests. Such tests, however, have been recently made on one very large system. Fig. 4 shows the diagram of connections. The tests consisted of switching the primary of the transformer on and off the busbars of the generating station with the secondary open circuited.

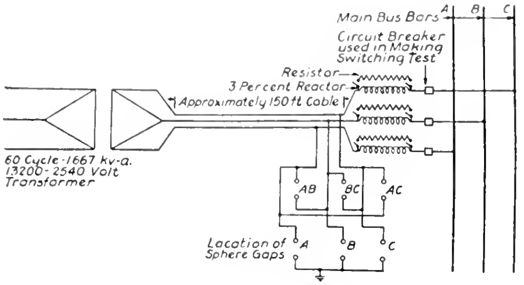

Fig. 4. Diagram of Connections Used in Switching Test. Transformers Switched Out of the Circuit

It will be noted that reactors are located between the primary of the transformer and the circuit breakers connecting the transformer to the busbars. These switching tests were made with and without the reactors shunted by resistors. Measurements by means of sphere gaps were made of the voltages between the lines connecting the transformer to the reactors and also from these lines to ground.

The sphere gaps used were limited in range to the measurement of a maximum of $3\frac{1}{4}$ times normal voltage. With the sphere set for this voltage arcing of spheres occurred, indicating that the transient voltages were of higher value than the voltage for which the spheres were set. Out of a large number of switching operations the number of sphere-gap arc-overs as a percentage of the total possible number of arc-overs has been determined for different setting of the spheres. This percentage of arc-overs has been plotted in Fig. 5, against the number of times normal voltage for which the spheres were set. The extrapolated portion of the curve which is dotted indicates that no arc-over would occur at a setting of the sphere gaps for 3.9 times normal voltage. With the resistor shunting the reactor similar readings were taken. In this case, the time allotted for making the test had expired before a determination had been made of the minimum distance apart, at which no sparking would take place, and therefore, these readings are plotted in the same manner as the first reading. The extrapolated portion of the curve indicates that no arc-over would occur at a setting of the sphere gaps for 2.6 times normal voltage. This shows that shunting the reactors with resistors lowered the voltage that the transformer had to withstand to less than 70 per cent of the value without the resistor.

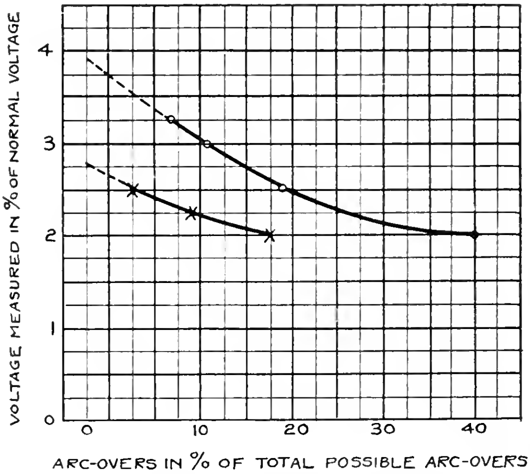

Fig. 5. Voltages Measured When Switching a Transformer Out of the Circuit

A large number of laboratory tests have been made in which operating conditions were duplicated as nearly as possible to determine the effectiveness of resistors shunting reactors in preventing high voltage from being built up, due to resonance.* In these tests voltages as high as ten times the generated voltage were built up between a line and ground due to resonance, but when the resistor was shunted across the reactor, this was reduced to less than double that of the generated voltage.

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* Published in a paper on "Voltage Stresses in Reactors," by F. H. Kierstead and R. Meeker in the Transactions of the A.I.E.E., 1920.

Edison Mazda Lamps in Lighthouse Service

By L. C. Porter

Commercial Engineering Department, Edison Lamp Works, General Electric Company

There are no lights in all the world of more importance than those in our lighthouses. Failure not possibly but probably means death to many. The author tells how electric lights are now replacing older forms in our lighthouses. The successes of the tests already made are best told by the fact that electric outfits for twelve of the principal districts have been ordered.—Editor.

At present, the majority of illuminants used as aids to navigation, by the United States Lighthouse Service, are oil wick lamps. In addition to these, there are a number of incandescent oil vapor lamps, and some oil gas lamps using mantles. Acetylene gas is the illuminant used in the next largest quantity, then come incandescent electric lamps, and electric arc lamps.

Fig. 1. Oil Post Lantern used in Lighthouse Service

There are several reasons why electric lamps have not come into general use for this class of service. Most of the lights are located along the coast, rivers and lakes, at points where electric current is not available. Absolute reliability is a factor of prime importance in lighthouse service, and the tendency of electric power lines and lamps to fail occasionally has been a serious detriment to their use in this class of work. The relatively high cost of power from batteries, and lack of suitable low-voltage electric flashing mechanisms have also retarded the use of electric lamps in lighthouse service.

During the past few years, however, conditions have been changing rapidly. Great advances have been made in the reliability and efficiency of electric lamps. The rapid increase in labor costs have made the use of oil lamps, which require frequent cleaning, trimming and filling, very expensive. The acetylene lamps are operated from large, heavy tanks of compressed gas. Large boats and several men are needed to remove these tanks and ship them back to the factory for refilling.

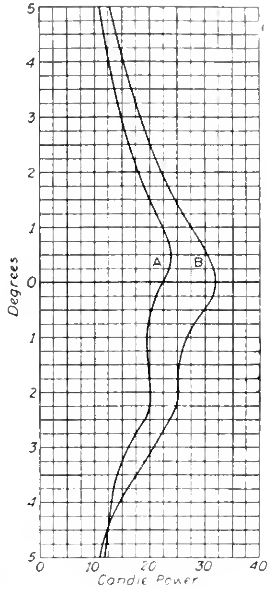

Fig. 2. Vertical Distribution Curves of Light from an Oil Post Lantern, with 200-mm. Pressed Lens, taken 90 deg. apart—narrow and broad side of flame. (A) Edgewise. (B) Flatwise. High flame used, perhaps higher than would be possible in practical use

In a number of cases these difficulties have been overcome by the use of electric lamps which have been applied very successfully to some of the larger lights located where electric power of commercial lighting voltages is available.*

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* "Lighthouses and Light Vessels," by Capt. S. G. Hibben, Illuminating Engineering Society's Transactions, March, 1923, Vol. XVIII, No. 3, p. 241-272.

The solution of the small light problem, however, has not been so easy, and no small amount of research has been expended on it. In determining what was necessary in the way of an incandescent lamp to replace the oil and acetylene burners, photometric tests were conducted on typical units. Vertical distribution curves were made on a new oil post lantern with a 200 mm. lens. This lamp is illustrated in Fig. 1. The curves are shown in Fig. 2, where *A* represents the edgewise and *B* the flatwise distribution. These show a maximum beam candle-power of 32 on the axis, and a spread of about 20 deg.

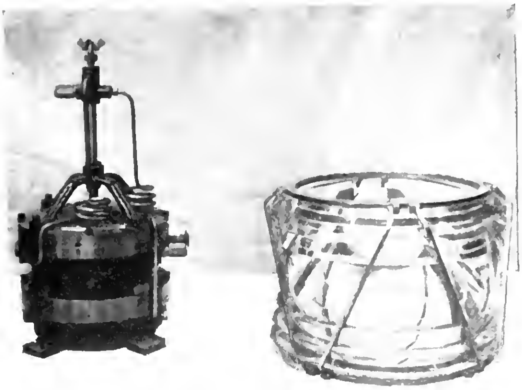

Fig. 3. One-half Foot Acetylene Burner and 200-mm. Lens for Lighthouse Service

Next, a typical 200 mm. lens equipped with a $\frac{1}{2}$-ft. acetylene burner lantern was tested, see Fig. 3. In this case a horizontal curve was taken as well as the vertical curve, see Figs. 4 and 5. These curves indicated a maximum beam candle-power on the axis of 56, and a spread of about 8 deg.

As both of these equipments were new, and adjusted to get the maximum light from the source, it was felt that any incandescent lamp which would give equal beam candle-power would be more effective in service, as it is well known that the average candle-power of oil lamps, under service conditions, falls considerably below their initial rating.

Experience in replacing oil signals by electric signals in railroad service had also shown that the characteristic color and steadiness of the electric light is such as to make a more effective signal at an actually lower candle-power of light source than maintains with the oil flame. Distribution curves made with a 10-volt, 0.5-ampere, Mazda lamp, see Fig. 6, with the 200-mm. lens, showed a maximum candle-power on the axis of 40, with a spread of about 4 deg., see Fig. 7. A study was made of the distances at which beams of different spread would strike the water from different mounting heights, see Fig. 8. From these data it

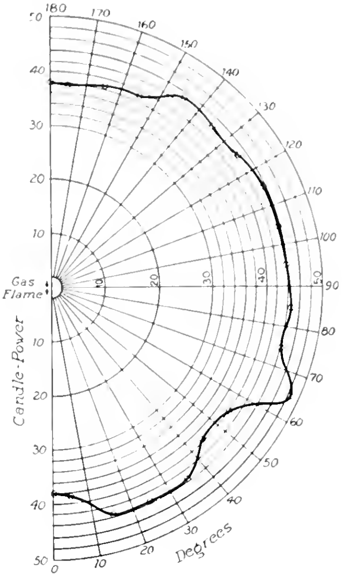

Fig. 4. Horizontal Distribution Curve of Light from One-half Foot Acetylene Gas Lantern with 200-mm. Buoy Lens

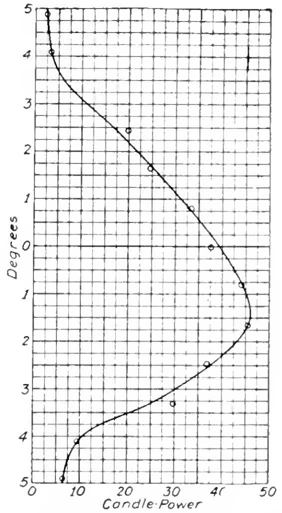

Fig. 5. Vertical Distribution Curve of Light from One-half Foot Acetylene Gas Lantern with 200-mm. Buoy Lens. Flame perpendicular to screen

seems apparent that the spread from an electric lamp will be ample to take care of the requirement. There is sufficient stray light in the lens to give a good indication when a ship is close to the light, but below the main beam.

Fig. 6. Ten-volt, One-half-ampere Edison Mazda Lamp for Lighthouse Service

While this work was under way, Mr. A. W. Tupper of the Lighthouse Department at Washington, was busy designing and developing an electric flashing device. This little flasher is a very ingenious device, having but two moving parts. It consumes only 28 watthours of energy per year, and can be set to give single, double, triple or quadruple groups of flashes at any desired rate between 20 and 60 per minute.

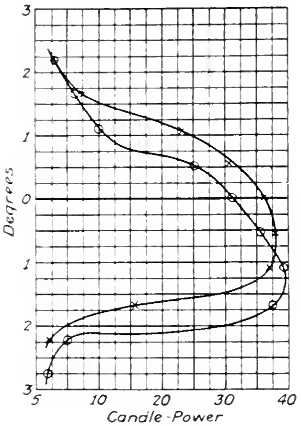

Fig. 7. Vertical Distribution Curves from Electric Lantern with 10-volt, $\frac{1}{2}$-amp. Mazda Lamp and 200-mm. Buoy Lens. Curves taken 90 deg. apart

The advantage of using a flasher is twofold. First, it reduces the battery energy consumption very materially over that required for a steady burning light. Second, the desired characteristics of certain flashing lights can be maintained, and lastly, a flashing light is more conspicuous than a steadily burning light.

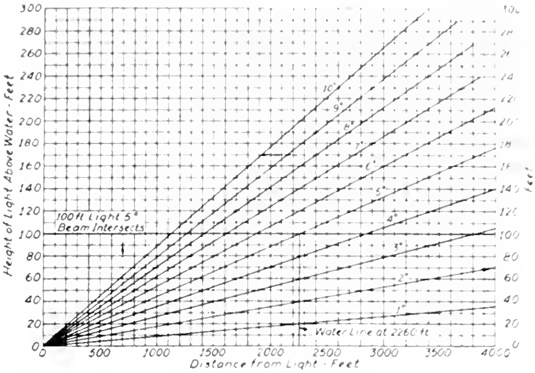

Fig. 8. Curves to determine:

(1) The distance from a light at which the bottoms of beams of various spreads and mounting heights will strike the water

(2) The height above the water of the top of the beams of various spreads and mounting heights at various distances from the light

(3) The distance from lights of various spreads and mounting heights at which the bridge of a ship passes out of the beam

DIRECTIONS FOR USE

Case 1. To determine the distance from the light at which the bottom of beams of various spreads and mounting heights will strike the water.

Instance: 100-ft. post and lantern having 5 deg. beam spread.

Directions: Follow out on the horizontal line of 100-ft. height above the water until it intersects the diagonal 5 deg. line. From this point or intersection follow the vertical line down to the scale giving "Distance from Light." The intersection of the vertical line with this scale will give the distance in feet that the lower edge of the beam of light having a 5 deg. beam spread and originating 100 ft. above the water will strike the water.

Note: For lantern mounted at heights other than 100 ft. and having beams of other than 5 deg. spread, substitute the required height and beam spread respectively in the above directions.

Case 2. To determine the height of the top of the beam above the water at various distances from the light and various mounting heights.

Instance: 3000-ft. distance, 3 deg. beams, 40-ft. mounting height.

Directions: From the scale at 3000 ft. follow a vertical line until it intersects the diagonal 3 deg. line. At this point of intersection follow the horizontal line to the right to the scale showing height above water and read the intersection in feet—80 ft. The height of the mounting post or 40 ft. added to this amount—80 ft.—will give the height of the top of the 3 deg. beam mounted on a 40-ft. post at a distance of 3000 ft. from the light which is 120 ft.

Note: For beams other than 3 deg. spread, distances other than 3000 ft. and mounting height other than 40 ft. substitute the required beam distance and mounting height in the above directions.

Case 3. To determine the distance from the light mounted on posts of various heights, at which a ship bridge of various heights will pass out of the beam.

A. Where the height of the bridge is greater than that of the post.

Instance: 50-ft. bridge, 20-ft. mounting post, 2 deg. beam.

Directions: Find the difference between the height of the bridge and mounting height 50 − 20 = 30 ft. Follow the 30-ft. line until it intersects the 2 deg. beam. Directly below this point read the distance in feet—1700 ft.—at which the bridge will pass out of the beam.

Note: For other bridge height, mounting heights and beam spreads, substitute in the above directions.

B. Where the height of the bridge is less than the height of the mounting post.

Instance: 20-ft. bridge and 80-ft. mounting post. Beam spread of 6 deg.

Directions: Find the difference between the height of mounting post and height of bridge, 80 − 20 = 60 ft. Follow the 60-ft. line out until it intersects the diagonal 6 deg. line. Read the distance directly beneath this point—1120 ft.—which is the distance at which the bridge passes out of the beam.

Note: For other bridge height, mounting heights and beam spread substitute in the above directions.

Incidentally, the use of this same little flasher with primary batteries makes practical electric highway crossing beacons throughout the country, in places where electric power service is not available.

While this work was under way, the Edison Primary Battery Company was cooperating with the Lighthouse Department in the development of suitable batteries for operating the lamps and flashers, see Fig. 9. Tests were made to determine the effect of very low temperature on the voltage maintenance of the battery, to make sure that it would function properly in Alaska.

Tests were also conducted with a lamp and flasher to determine the effect on the voltage curve of intermittent burning service. These tests showed that either the 500- or 1000-ampere-hour cells will function satisfactorily even if exposed to zero temperature, using a ¼-ampere load. If, however, ½- or 1-ampere lamps are to be used, some protection should be afforded the cells, such as placing them in a battery box buried in the ground.

The incandescent lamps used are designed to outlast the life of the battery with a factor of safety, and the practice is recommended of renewing the lamps at the time the battery is renewed. Incandescent lamps, however, are not absolutely infallible. Occasionally, a lamp will burn out before its allotted time. To guard against this contingency, Mr. Tupper designed a relay which, in case one lamp fails, will automatically light a second lamp in a lens placed just above the first one. In this manner practically infallible service is assured.

In order to secure further economy in battery energy, and to increase the length of renewal period, the American Gas Accumulator Company has developed an electric sun valve, see Fig. 10, similar to the one which has been in use for many years on gas outfits. This device automatically opens the circuit and thus extinguishes the lamp with the approach of daylight, and lights it again on the approach of darkness.

One of the questions raised in connection with the substitution of electric for gas and oil lamps, was that of ice and sleet. It was felt that possibly the greater heat of the flame sources would keep the lens freer of ice than would the electric lamp at points just below freezing. This is probably true. However, tests were conducted on an electric outfit, 10-volt, ½-ampere lamp and 200 mm. Fresnel lens, free from ice, and then the same outfit covered with a ¼-in. coating of rough ice. This was found to increase the spread of the beam slightly, and to reduce its maximum candle-power on the axis about 50 per cent. The average candle-power throughout the beam, however, was reduced only 14 per cent.

After all this preliminary research was completed, an actual installation was made at the 3rd Lighthouse District at Tompkinsville, Staten Island, N. Y. An electric outfit using a 10-volt, ½-ampere Edison Mazda lamp was installed alongside a gas outfit having a ½-ft. acetylene burner and an oil post lantern. The electric outfit has been in successful operation now for nearly a year. Reports made by the Technical Assistant at the depot, on the effectiveness of this light, read in part as follows:

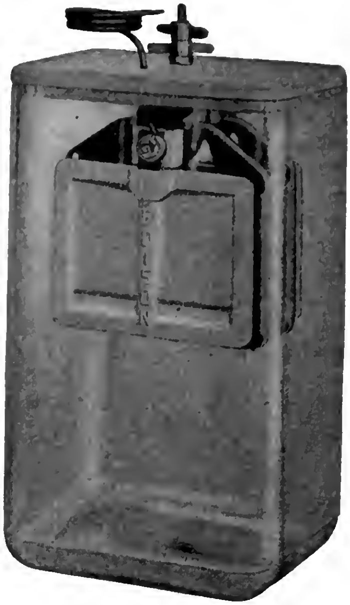

Fig. 9. Five-hundred Ampere-hour Edison Primary Battery

"In the evening the three lights were observed from the upper deck of the municipal ferry, from locations on the viaduct leading to the ferry station at St. George, from locations on the terrace, at the depot, and from various locations on the depot docks. The evening was rainy and the visibility below normal. On the trip from Manhattan to Staten Island the electric lantern was first observed when the ferry was about opposite Robbins Reef Light. The acetylene lantern was not seen for several minutes, or until in fact the ferry had almost reached the slip. As observed from the viaduct, the electric lantern appeared more than twice as bright as the acetylene lantern, and from the terrace the electric lantern was still unmistakably brighter. From positions on the docks there was not much choice between the two lights, but whenever there was any difference, it was in favor of the light given by the electric lantern.

Fig. 10. Electric Sun Valve of the American Gas Accumulator Company

"On the following evening, July 19th, the writer observed the three lights from the upper deck of the Brooklyn ferry, and also from various elevations on the depot coal tower. In going across toward Brooklyn the acetylene light gradually disappeared from view, while the electric light was still plainly visible. On returning from Brooklyn, the electric light was picked up first, and by a comparison with the location of other lights on the shore, the writer is fairly certain that the electric lantern was observed as soon as it came within the range of vision from behind the cotton docks. The acetylene lantern was not observed until the ferry was more than half way across the Narrows. From all points when the two lights were visible, the electric lantern was much the brighter. On account of the post lantern being a fixed light, the writer was not able to distinguish it from the other shore lights, so that it was not possible to compare it with the flashing lights at any distance. Observations made from the viaduct seem to indicate that the intensity of its light lay in between the other two. On the occasion of this trip, observations were also made with marine glasses, and it was found that in this case the advantage of the electric lantern was not nearly as marked, its short flash giving more difficulty when the glasses were used. It is also believed that the greater visibility of the electric lantern is not so much due to a greater candle-power, as the laboratory tests made by the Edison Lamp Works indicated that it did not have a greater candle-power, but that this increased visibility is due to the fact that we have a smaller source of higher intrinsic brilliancy. The observations made from the coal tower indicated that at that short distance, when appreciably below the level of the lantern, both lights were about equal; when viewed approximately on the level of the two lanterns the advantage was decidedly in favor of the electric lantern. When viewed from elevations considerably above the lanterns, the acetylene lantern was the brighter.

"On the evenings of July 20th, 21st, and 24th the writer made further observations of these lanterns from the deck of the municipal ferries. On one occasion when visibility was good, the electric lantern was first picked up while the ferry was about opposite the Statue of Liberty, whereas the acetylene lantern could not be observed until the ferry was nearly opposite Robbins Reef Light. On another occasion of lower visibility the electric lantern was first picked up when the ferry was eleven minutes from the Manhattan shore, whereas the acetylene lantern was not discerned until six minutes later. The total trip occupied about twenty-two minutes. Observations were also made on trips when the ferry was bound toward Manhattan. In these cases the acetylene lantern was always lost from view long before the electric lantern."

Electric installations have been ordered for each of the 12 principal districts. These, undoubtedly, will be followed by many more, thus establishing the entrance of the Mazda lamp into another field—that of guarding human life and property on the water.

The advantages of the electric outfit are marked. Greater reliability is assured. It not infrequently happens that other illuminants, particularly those on buoys, are extinguished by being pushed down under the water either by boats or ice. The electric lamp will not be extinguished by such submersion.

The electric outfit does not need to be visited every few days by a tender. It will operate about a year without attention, thus bringing about a large reduction in operating cost. The oil lamps cost about $15.00 per month, per light, for maintenance labor, in addition to burning one quart of oil a day, costing from 30 cents to 35 cents per gallon (specially selected, high grade kerosene oil is used), as well as the expense of chimneys, burners, etc.

The acetylene lamps require a large lighthouse tender and crew costing about $300.00 a day to handle the renewals of the heavy gas tanks, whereas the simple battery and lamp renewals can be handled by one or two men in a motor boat at a cost of about $30.00 per day. The electric outfit will cost about $18.00 per year for batteries, and about $1.00 for lamps.

In addition to this saving and greater reliability, a more effective light is obtained.

Cargo Winches for Merchant Ships

By C. H. Giroux
Electrical Engineer, U. S. Engineer Dept., Washington, D. C.

This comprehensive article on cargo winches for merchant ships deals with all the important considerations which enter into an intelligent selection of equipment.—Editor.

When selecting equipment for a merchant vessel, the first consideration is always the class of service for which the ship is fitted. Although not always recognized, this applies fully as much to the deck winches as to any other machinery.

On a passenger ship the winches are used only for putting supplies aboard, or for handling baggage, and then for comparatively short periods of time. Obviously duty of this character does not demand a winch of the same capability as one used for loading and unloading a freight vessel. On the other hand, noise may be a very vital factor on the passenger vessel, and of little consideration on the freighter.

There are similar conditions which must be observed when supplying equipment for tankers, barges, yachts and other types of vessels.

Considerations too numerous to mention all have a bearing on this subject, but the most important may be cited as the trade in which a vessel is employed, the methods used in the different world ports, the facilities for delivering and disposing of cargo and possibly the most important of all is the character of the commodities carried.

It would not be wise to fit a ship with deck machinery suitable for a certain trade, if at a later date it would be called upon to run in another trade, such that this machinery would be inadequate. It is seldom known at the outset in what trade a cargo vessel will be called upon to operate during its life, and it is therefore usually necessary to fit it with machinery which will meet the most severe requirement for a ship of its class. Occasionally we find ships designed for a special purpose, such as refrigerating ships, and here we may take full advantage of the peculiarities of this service when selecting the equipment.

The financial success of a freight vessel depends to a considerable extent upon the rapidity with which the cargo is loaded or discharged. The application of proper winches to ships of this class handling general cargo in all ports of the world, is, therefore, a very important matter and worthy of considerable study by both the manufacturer of the winches and by the shipbuilder.

The remainder of this article will be confined to this application, assuming that if the same principles are followed, there will be little likelihood that inadequate equipment will be supplied where the duty is comparatively light and much easier to determine.

There are many factors affecting the duty imposed upon a general cargo winch, of which the following are the most important:

1. Design of vessel
2. Kind and weight of cargo
3. Number of stevedores working
4. Facilities for disposing of cargo
5. System of handling
6. Weather conditions.

The features in the design of the vessel which influence the operation of the cargo winch are briefly—depth of holds, heighth above the water line, distance from center line to side of ship, size of hatches, arrangement of booms and winches.

The first three dimensions determine the time during which the load is hoisted, lowered, and transferred to or from the wharf. Assuming that the time for hooking, unhooking and preparing loads is fairly constant for a given cargo, the duty on the winch is directly proportional to the distance traversed between the wharf and ship's hold.

The size of the hatches has a decided effect on the dispatch with which certain kinds of cargo can be handled. For example, it is very difficult to load lumber into a ship having small hatches, considerable time being consumed in getting the load into position for lowering. On some ships very large hatches are provided, so that two pairs of winches for each can be used, one pair discharging to the wharf, and the other to lighters.

The arrangement of winches and booms should always be so that the lines will spool properly on the drums, and that the lines will not be in the stevedores' way, else considerable time may be wasted.

When the weight, dimensions and character of the loads handled are uniform, the duty cycle to be performed by the winches can be quite accurately determined, and a design made which will do the required work in the least possible time and with the greatest efficiency. However, the cargo winches on a general cargo vessel may be called upon to handle any one of over twenty-five hundred commodities put up in various ways. This means that such a winch should be so designed that it will attain its greatest efficiency when handling the average cargo, but it must also have capacity and speed control for successfully manipulating loads of minimum and maximum bulk and weight.

This would appear to be an almost impossible task when considering, for the first time, the enormous variety of commodities. However, the mere fact that these articles have to be shipped and handled at a reasonable cost has compelled the manufacturers to send out their products in more or less uniform packages. These packages are usually grouped in slings, etc., so that the average winch load is between 1500 and 2000 lb. Less than two per cent of the commodities, when packed for shipment by water, weigh 6000 lb. or over. These heavier loads are usually grouped in one hatch so that it is not a difficult matter to rig additional falls for handling them. The consequent low speed is not a serious handicap because these loads are such a small percentage of the total cargo and also because these heavy packages are handled slowly and carefully by the stevedores.

From the above, it would appear that a winch having a maximum capacity of 6000 lb. or over, and capable of reaching its maximum cargo handling efficiency at approximately 2000 lb., fully meets the load requirements for general cargo work.

Assuming that the winches are able to transfer cargo somewhat faster than the stevedores can prepare the loads and stow them on the wharf, or in the ship's hold, the tonnage attained will vary directly with the number of gangs employed in this work. There is, however, a limit to the number of men which can work without interference with each other.

The usual practice is to station four gangs, one at each corner of the hatch, and to distribute the loads to them in rotation. This arrangement may be varied according to the size of the hatches, kind of cargo, etc. The winch must, however, be capable of keeping ahead of the maximum number of stevedores which may be used.

The facilities for preparing hook loads, or for disposing of cargo on the wharf is a very important factor, affecting the tonnage handled, and consequently the duty imposed on the winch. Here again we must assume the most favorable conditions, so that the winch will not be blamed for delay. We can allow only a reasonable length of time for hooking, or unhooking the load and assume that the hook will be in motion the remainder of the time.

The system employed in handling a load, especially the method of transferring it between the center of the ship's hatch and the wharf, influences the duty imposed on the winch. The greatest tonnage rate can be obtained by selecting the method most suitable to the cargo. With some methods, one winch does considerably more of the work than its mate, and must not fail under this unequal distribution of labor.

Because of the fact that certain laborious duties in the handling of cargo must be done manually, the weather conditions have a decided effect on tonnage rates. It is reasonable that a man will do considerably more work in a moderate temperature than when it is either extremely hot or cold. The statement is often made that electrical winches on ships running into tropical ports must have motors of extra capacity because of the high initial temperature. Because of the slower working of the cargo by the stevedores, it may be well assumed that if the winch has tonnage capacity to meet all other requirements, it will perform successfully under tropical conditions.

Most of the above conditions have been established by many years of experience in shipping and as long as existing methods are used, the ship's winches must meet these requirements.

The following characteristics have an important bearing on the ability of a winch to handle cargo under the conditions outlined above:

1. Reliability
2. Mechanical efficiency
3. Maximum load which the winch can hoist
4. Rope speed at average load and at no load
5. Thermal capacity.

Unless every part of the entire system of cargo handling machinery is thoroughly reliable, it has no place on a vessel of the kind we are discussing. A failure of one winch will usually mean that operations in one hold of the vessel cease, and a continued delay will mean that the vessel will have to stay in port an extra day or more. The value of a ship's time may be several thousand dollars a day, and the loss due to failure of the winches is out of all proportion to the cost of repairs or to the first cost of the apparatus.

The mechanical efficiency of the various parts of the winch affect the maximum load capacity, the rope speed, and if motor driven, the thermal capacity. The efficiency of the various parts should therefore be made as high as possible consistent with reliability giving proper regard to weight, space and first cost.

When considered alone, it would seem that the maximum load capacity of a winch should be great enough to enable the winch to lift any piece of freight which it is likely to encounter. This would mean either that the motive power would have to be abnormally large, or that the rope speed would be abnormally slow. Both of these factors are of such great importance that the maximum load capacity is of secondary consideration. As explained above, a winch having a maximum capacity of 6000 lb or over should be satisfactory for general cargo work. This does not mean that the winch should only have capacity for exerting this pull momentarily, but must be capable of handling these loads continuously at a good tonnage rate.

The question of rope speed for general cargo winches is of greatest importance, and is the subject of a great diversity of opinion. Theoretically the rope speed should be just high enough so that the hook will always be at the point of loading at the exact moment that the load is ready. In this way the maximum tonnage output would be obtained with maximum efficiency. However, this ideal can not be attained in practice, and the rope speed must be chosen so that the load will never be waiting for the hook on account of the time consumed in completing the cycle.

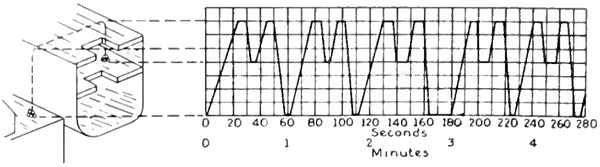

Fig. 1. S. S. *Steel Ranger* Receiving Barrels of Ammonium Chloride. Three barrels (810 lb.) per draft. Tonnage rate 24 tons per hour

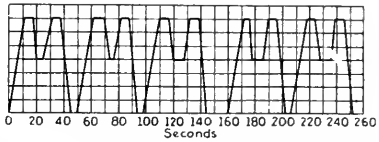

Fig. 2. Theoretical Effect on Cycle shown in Fig. 1 of Increasing Rope Speed Hoisting to Correspond with that of Electric Winch Geared for 250 ft. per min. with 2000-lb. Load. Tonnage rate 26 tons per hour

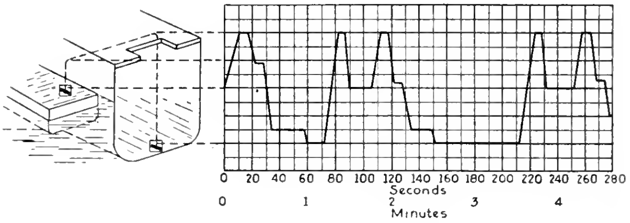

Fig. 3. S. S. *Steel Ranger* Receiving Steel Plates from Lighter. Average tonnage rate 13.25 tons per hour

This cycle always consists of four distinct elements: hoisting the load, lowering the load, hoisting the light hook, lowering the light hook. It is therefore evident that the rope speeds lowering loaded and light and the speed hoisting the light hook are just as important as the speed of hoisting the load, although the latter is usually the only one specified by the purchaser. This practice has arisen through the use of steam winches where these speeds only are limited by the safe engine speed. With electrical winches, however, further attention should be paid to these speeds as they may vary greatly depending on the motor characteristics and method of control.

Observations taken on a large number of vessels loading and discharging in various ports indicate that a rope speed of 250 ft. per minute when hoisting the average load is sufficient. Little or no time can be saved by providing a higher speed than this, and the first cost of the apparatus and the power consumption increase rapidly with an increase of speed.

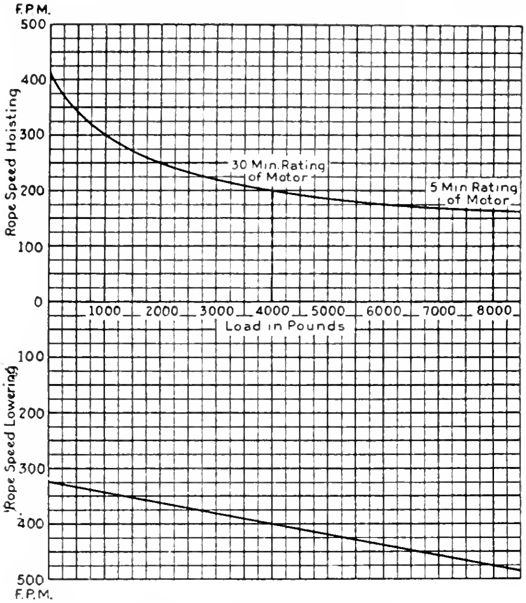

Fig. 4. Load-speed Curves of Electric Cargo Winch with 35-h.p. 30-min. Series-wound Motor

Fig. 1 illustrates a typical cycle of operation where the loading and unloading of the hook is done very quickly. Here the rope speed in hoisting from the pier was necessarily slow on account of interference with the pier shed. The rope speeds used in the operation were not the maximum of which the winches were capable, and thus gearing for higher speeds would not increase the tonnage rate.

Fig. 2 illustrates the theoretical effect of increasing the rope speed in hoisting, assuming that interference with the pier shed could be avoided. The tonnage rate would then be increased 17 per cent.

Fig. 3 is a good illustration of the winch performance when handling unwieldy loads, The winch is idle a great percentage of the time while drafts are being prepared and stowed. The rope speed here is of little consequence, as one or two seconds reduction in running time would only mean a longer wait at the destination.

Fig. 4 shows calculated values of rope speeds, both hoisting and lowering, of a cargo winch equipped with a 35-h.p. series wound motor and well designed dynamic braking control.

The facility with which the operator can perform the various operations has some effect on the amount of cargo handled. A few seconds delay on each operation will amount to many hours during the loading or unloading of a ship. The winch builder who provides a control which is easy and simple to handle will get the good will of the stevedore and this may not only influence the tonnage rate, but also may have a far reaching effect on the use or abuse which the equipment will receive.

Experience has proved that the greatest rapidity with the Burtoning system can be obtained where one man operates both winches. This is because he can anticipate subsequent movements, and therefore can stop or start each winch at exactly the right moment.

In order to take advantage of this condition, controllers for cargo winches should be arranged so that one man can operate two winches with ease. This can best be accomplished by a design having horizontal levers, one for each hand. The upward direction should hoist, and the downward direction should lower the load.

With electric winches overload protection for the motors should be provided so that in case the controller handles are moved too rapidly, the equipment will not be injured. These protective devices should be arranged to reset automatically when the controller handle is moved to the off position. The overload setting should always be under the supervision of the ship's electrician and should be proof against tampering by unauthorized persons.

With electric winches, the cargo handling capacity is limited by the ability of the motor to dissipate the heat generated in the windings, bearings, etc. For instance, we may have two motors with exactly the same characteristics and geared for the same speed at the same average load. One of these motors may be rated at 35 h.p. for 30 minutes and the other 35 h.p. for 15 minutes. If we should operate these two motors on the same duty cycle for an extended period of time, we might find that the 30-minute rated motor would never exceed a safe ultimate temperature, while the 15-minute rated motor would in time reach a temperature which would be injurious to the insulation.

Thus, it will be seen that the horse-power rating is not sufficient to determine whether the motor will perform the required duty. The time rating must always be considered, or preferably, the characteristics of the motor should be analyzed with reference to the most severe duty cycle likely to be encountered in the handling of cargo. With steam winches, the thermal capacity does not enter; but with electric motors, it is important. A good rule to follow is to fix as the maximum load, that which the motor can hoist continuously for five minutes.

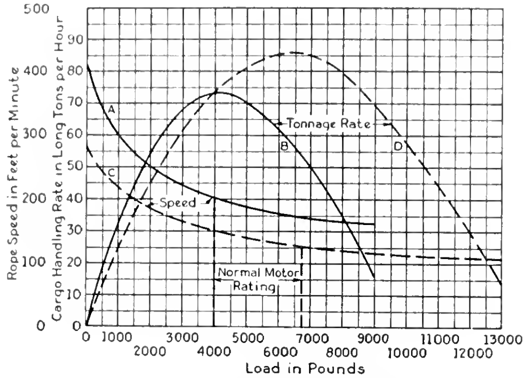

Fig. 5. Cargo Handling Capacity of Deck Winch Using 35-h.p. 30-min. Series-wound Motor. Tonnage rates are maximum obtainable on continuous duty with 55 deg. C. rise on motor on following duty

Duty Cycle—Burtoning system used for unloading ship
Curves are for inboard winch
Hoist from hold 40 ft.
Transfer to dock 38 ft.
Lower to dock 30 ft.
Return light hook to bottom of hold

Referring again to Fig. 4, we find that with the gearing selected, the motor will exert its normal horse power at 4000 lb., but will be able to hoist 8000 lb. at its five-minute rating. The maximum capacity of this winch should, therefore, be limited to 8000 lb.

The gearing which is selected for an electric winch has a decided effect on the thermal capacity as may be seen from Fig. 5.

Curve "A" is the load-speed curve of a winch geared to handle 2000-lb. loads at a speed of 250 ft. per minute, and curve "B" is the corresponding tonnage rate curve when performing a definite duty cycle. The rates given are the maximum which can be obtained on this cycle of operations without exceeding the allowable temperature rise on the motor.

It will be noted that the maximum tonnage rate on curve "B" occurs at 4000 lb., which means that the winch is operating at its maximum overall efficiency at this load.

By changing the gear ratio so that the rope speed at 2000 lb. is 185 ft. per minute as shown on curve "C," we get tonnage rates as shown on curve "D." Here the maximum rate occurs at 6500 lb.

This shows that a decrease in rope speed has the effect of increasing the tonnage rates at heavy loads, but decreases them on light loads.

Inasmuch as we are most interested in average loads of about 2000 lb. for general cargo work, it would at first appear that we should select a gear ratio which would give the maximum rate at this load. However, a further increase in rope speeds beyond those shown in curve "A" results in rest periods with light loads, which are too short for hooking and unhooking most kinds of cargo. The result is that the winch remains idle for longer periods and consequently the tonnage is not materially increased.

The above results show the desirability of selecting a gear ratio which will give the highest tonnage rate with the least expenditure of energy and the consequent minimum size of electrical equipment. This can be done only by carefully comparing the duty to be performed with the motor characteristics.

Studies in the Projection of Light

PART V

METHODS OF COMPUTING FLOODLIGHTING

By Frank Benford

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The problem of floodlighting a building or other object is by no means as simple as it might appear. The number of floodlights necessary, their locations, intensities, and direction of beams are collectively dependent on the size of the object, its color, perspective, and the distance between each floodlight and the surface it illuminates and the angle with which each beam meets the surface. All those factors must be properly correlated to secure satisfactory results. The flux and the single-unit methods of computation are first explained in the following article and their shortcomings pointed out. An improved method, that employing spherical projection, is then described and applied to the solution of two typical problems.—Editor.

Nature of Floodlighting Problem

The gains in lamp efficiency during recent years have made it practical to illuminate large areas of wall or ground by beams of light projected for considerable distances. There is a strong tendency toward larger and larger units; and while the general efficiency is thus raised, and the possible applications much extended, the large size of the individual floodlight sometimes increases the difficulty of obtaining the proper distribution of light. It often happens that due to limited current capacity, or more often to limited funds, the strictest economy of projection is desired, and a close examination of engineering details is necessary. In making this examination certain problems in solid geometry arise, and the ordinary methods of perspective drawing do not always yield simple and accurate data. In many cases plain perspective becomes hopelessly involved, and the special type of perspective drawing which will shortly be described is intended to simplify and shorten the design work so that a prompt solution can be made of even the more difficult cases.

Floodlighting might be divided into three classes:

(1) Spectacular illumination for expositions, fairs, and conventions, where the competition from street lights and signs may make it necessary to have high average illumination in order to secure effectiveness.

(2) Sign lighting, which is often simplified by dark surroundings.

(3) Strictly utilitarian floodlighting, such as illuminating a factory fence line or the deck of a ship during loading or unloading.

Not only does each type of floodlighting require different treatment, but each individual case is apt to have certain peculiar features that require special attention. Note is made of these distinctions because the name "floodlighting" suggests a large quantity of light that simply floods the illuminated object more or less regardless of size, distance, or the angle of view.

A number of years ago, when preliminary work was being done for an international exposition, a building facade some 140 ft. long by 60 ft. high was illuminated by a small group of lighting units placed about 70 ft. from the building. To an observer standing near the source of light the illumination appeared to be of high uniformity; but an exploration over the face of the building with a photometer showed variations in illumination of ten to one. But if the observer went several hundred feet from the building the variations not only became visible, but actually objectionable. The difference here was entirely in the eye of the observer. In the first case he could not see the entire facade in a single glance, and in the brief part of a second necessary to look from one corner to another, the impression of brightness would fade, and, to the casual observer certainly, the illumination would seem uniform. At a greater distance the entire facade could be included in a single glance and the high and low areas of illumination became distinct. Thus in this particular case the point of view of the observer becomes of the utmost importance, for in spectacular lighting things are what they seem, and if the eye is satisfied then computations are vain and photometry is an idle thing.

In the present installment attention will be confined to incandescent floodlights with plain glass doors. There are various lens doors made for dispersing the beam in one or more directions and by the use of these doors the beam may be made to assume different cross sections. Arc lights have also seen wide and successful use as floodlights for facade illumination, and when equipped with diverging door strips the resultant beam is ideal in many respects. Discussion of these optical devices will be reserved until more attention can be given to several interesting optical characteristics of the dispersed beam.

The Flux Method of Computing Floodlighting

The simpler cases of floodlighting may be solved by mental arithmetic. Thus if an area of 1000 sq. ft. is to be illuminated to 6 ft-cd., three floodlights giving 2000 lumens each will be sufficient. This elemental way of arriving at results is certainly rapid enough, but there are often unsuspected elements of danger in it. Plans so made will be successful:

(a) *If* the beams of light can be so overlapped that no dark spots will remain,

(b) *If* the beams can be distributed so that the near and far sections are of equal apparent brightness, and

(c) *If* the beams can be arranged so that the light will not be unduly wasted around the edges of the surface.

Items (a) and (b) will be recognized as opposing characteristics, for if the beams are placed close enough together to secure continuous illumination there may not be enough beams to cover the entire surface; and if the distribution can be made to satisfy both (a) and (b) then the loss around the edges of the illuminated area may be so great as to lower the average illumination below the desired level. There are a variety of floodlighting units of various beam diameters and volumes of light that are available and intelligent choice of both number and types of units usually requires more data than are given by the method just outlined.

Method of Computing Floodlighting by Single Units

When only a few beams are to be used it is often best to investigate the individual action of each beam, finding what area is covered and how the illumination varies from point to point in the beam. Perhaps the most common case that arises is the attempt to illuminate a large poster board with a single floodlight placed rather close to one end. This is a type of installation that is not to be recommended, but it frequently cannot be avoided, and to make the best of circumstances the field of illumination should be at least outlined if not fully explored.

The following symbols are used in the equations for the area illuminated by a single floodlight:

$2b$ = total angular width of beam

a = angle at which axis of beam strikes surface

D = distance between the point where the axis strikes the surface and the foot of the normal

L = length of illuminated area

W = width of illuminated area

P = perpendicular distance to illuminated surface

H = length of axis of beam (mirror to surface)

e = the ellipticity of the illuminated area

The angular width of the beam, $2b$, the perpendicular distance P, and the angle of inclination are ordinarily known, and the others can readily be derived by the aid of the following equations:

$$H = P \sec a \qquad (87)$$

$$D = P \tan a \qquad (88)$$

$$L = P\,[\tan\,(a+b) - \tan\,(a-b)] \qquad (89)$$

The ellipticity of the illuminated area is

$$e = \frac{\sin a}{\cos b} \qquad (90)$$

If the entire beam is received on the surface then e is less than unity and the area is elliptical in form. If the beam is projected almost in line with the surface so that the outer ray is parallel to the plane of the surface, then $a+b=90$ deg. and $e=1$, that is, the illuminated area is a parabola stretching to infinity, but the usefully illuminated area is concentrated near the vertex of the parabola, and the farther sections of the parabola are without engineering significance.

When the outer ray diverges out from the plane of the surface then the illuminated area is a hyperbola and the useful light may fall to a low percentage of the total projected light. It is seldom that we deal with any except the elliptical area.

The width of the ellipse is

$$W = L\sqrt{1-e^2} \qquad (91)$$

and the area is

$$A = \frac{\pi}{4}\,W\,L \qquad (92)$$

Even when the entire beam is incident upon the surface, the area covered cannot always be considered as illuminated on account of the large variation between the intensity at different points. As an example, in Fig. 40 is given the illuminations at the ends of the elliptical areas illuminated by the same floodlight at various angles. The illumination at the point where the axis of the beam strikes the surface is taken as 100 per cent in each case. When the beam is incident at near the normal the illumination curve resembles the beam-candle curve, that is, the illumination falls off to 10 per cent at the point where the edge rays of 10 per cent the central intensity strike. At high angles of incidence the near ends of the ellipse is much brighter than the far ends, and the brightest part of the illuminated area is near the point where the axis strikes, but slightly closer to the near end of the ellipse. Taking the typical case of a beam 11 deg. wide incident at an angle of 60 deg., the near end of the ellipse has a brightness of 15.7 per cent of the axial intensity while the far end has an intensity of only 6.1 per cent. These variations have the effect of making the effectively illuminated area come slightly back from the computed outline, and therefore in applying a beam to some particular area it is best to overshoot slightly.

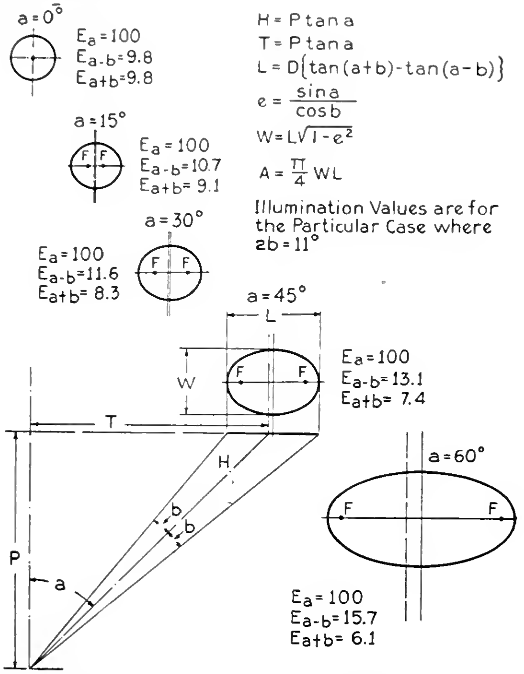

Fig. 40. Diagram Showing the Size and Shape of the Spot of Light Projected on a Surface from Various Angles by a Conical Beam 11 Deg. Wide

This particular floodlight gives almost the best uniformity of any on account of its narrow width. A wider beam at even low angles of axial incidence will give greater variation in illumination, and if the spread amounts to 40 or 50 deg. the floodlight cannot be used economically except when nearly normal to the surface.

The Spherical Projection Chart Method

In making plans for floodlighting any considerable area, the illuminating engineer is as often as not embarrassed by the number of variables entering the problem. If only a limited number of lighting stations are available, the variables are reduced in number but there still remain the choice of lighting units, the number required, and the focal adjustment of each. When the number of floodlights reach a total of 50 or 100, it becomes a serious problem to make an adequate preliminary layout of the proposed illumination for each floodlight must be treated as an individual, otherwise the engineer may find himself in the unhappy position of having plenty of light but not being able to distribute it properly.

The usual orthographic scheme of projection is useless for floodlight plans of any great size. Actually each individual beam illuminates an individual elliptical area, and each ellipse has its own major and minor axis, its own ellipticity and its own orientation. Orthographic drawings would of course represent each ellipse faithfully but this very faithfulness defeats the purpose.

Perspective drawings (or a photograph) come one step closer to usefulness, for if the point of view (or the camera) is at the lighting station then each floodlight beam is represented by a circle, but the diameter of each circle depends upon the angle at which the beam strikes the projection plane of the drawing. In general each beam will be represented by a circle of different size, but a group of circles even if to different scales will be vastly more tractable than a similar group of ellipses. As an illustration, the three circles *A*, *B*, and *C* in Fig. 41 show the area illuminated by beams of equal diameter. The diameter varies as the distance to the plane of projection and as a result the beam to the top of the tower has a circle diameter three times as great as the beam to the adjacent corner. In order better to compare the three they are drawn separated from the drawing as *A′*, *B′*, and *C′*.

A spherical surface with the lighting station as a center would make an ideal surface on which to make the layout, for then each beam would trace a circle of a diameter directly proportioned to its angular width and the variable scale of the plane perspective drawing would be eliminated. Of course a spherical drawing surface is hardly a practical affair, but there are a number of ways of representing a spherical surface on a flat surface.

Occasionally a map of the world is seen in which half of the entire surface is present and which has parallels of longitude converging to points at the north and south poles. On these maps the lines of latitude make a half-hearted attempt to curve about the poles and this represents an effort on the part of the cartographer to lessen the form-distortion of the countries lying near the boundaries of the map. This curving of the latitude lines restores the outlying lands to recognizable form, but it changes the area scale, which is in our present case the very thing we are trying to avoid. By leaving the lines of altitude run parallel to the equator the areas are correct in size but distorted in outline.

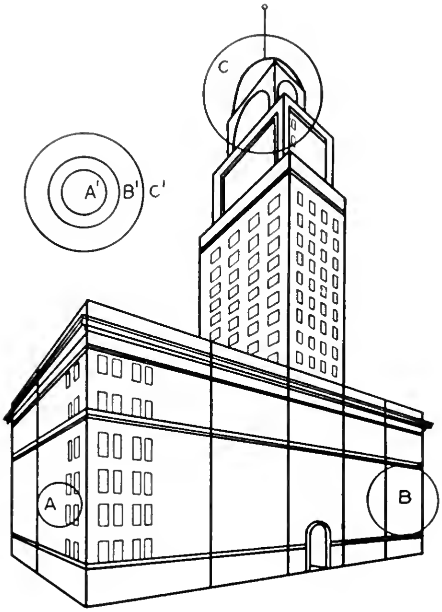

Fig. 41. Plain Perspective Drawing of a Building. Circles *A*, *B*, and *C* indicate the size of the spot of light that would be cast on those portions of the building by a floodlight of fixed spread. This variation in scale makes the perspective type of drawing difficult to use for making preliminary layouts

We usually need less than a hemisphere for projection purposes and we are at liberty to make our drawing in the center of the web where distortion is least. In Fig. 42 the spacing of the lines of longitude is proportional to the cosine of the altitude. Thus at altitude 60 deg., where the cosine is 0.5 the distance between the lines of latitude is half the distance at the equator.

The distortion is zero on this chart at the center and along the vertical and horizontal axes, but where the longitude lines depart much from the vertical the circular section of a beam would be plotted as an ellipse as illustrated in the upper left corner of Fig. 42. The scale of the drawing remains unaltered, say 10 deg. to 1 in., but a distortion takes place in the horizontal directions. It is therefore best to keep the drawing as near the center of the web as possible by shifting to right or left, but the vertical position must be left in the position it takes according to the vertical scale of degrees.

The semi-circular web in the center of the chart is used to plot the ground plan of the structure to be illuminated, placing the building in its proper relation to the lighting station which has a fixed position at the center of curvature of the concentric circles. If more than one lighting station is used, the layout must be repeated for each. Radial lines from the lighting station through the corners and other selected points of the ground plan and extended to the stub scale of degrees will give the angular relations between the vertical planes passing through the points. Both the stub scale on the ground plan web and the horizontal degree scale on the projection web proper are left unmarked, so that the projection can better be located near the center of the projection chart.

Two angles are sufficient to locate definitely any point on a sphere just as a point on the surface of the earth is fully located by its longitude and latitude. The ground plan is laid out to one of the two linear scales extending to the right and left of the lighting station, giving the scale some convenient value at the points marked *A* and *B*. The curves at the bottom of the chart are then also given a corresponding value where marked *A* and *B*. These sets of curves are simply tangent curves plotted to the vertical degree scale down the center. Thus a line through a point 300 ft. from the lighting station and 300 ft. high obviously has an elevation of 45 deg. regardless of its direction in azimuth from the point of sight. The point may be anywhere on a semi-circle 300 ft. from the center of the ground plan web, and a perpendicular dropped from the end of the semi-circle will intersect the 300 ft. tangent curve on a level with 45 deg. on the stub scale of degrees. The latter scale is

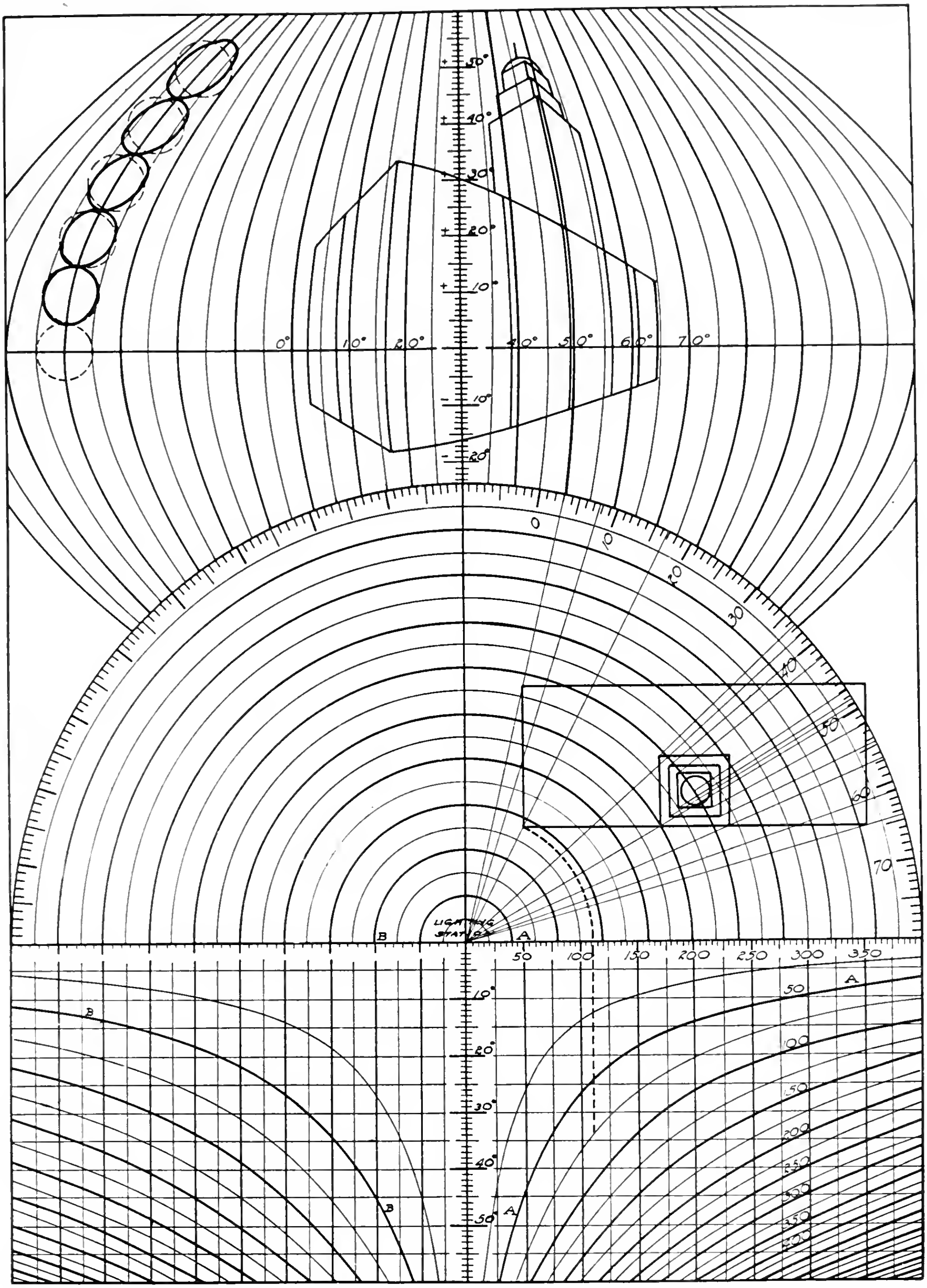

Fig. 42. Spherical Projection Chart Applicable to any Floodlighting Calculation; Here Applied to the Solution of the Problem Described in the Article

exactly duplicated by the scale on the projection web, and the point can now be plotted. It should be noted that 45 deg. elevation is the same height regardless of azimuth (longitude) which is the variation from map practice previously noted.

of the different sections. In the particular example chosen the end elevation, 125 ft. long and 112.5 ft. high, is divided into two 62.5-ft. sections, and the front facade, 300 ft. long by 112.5 ft. high, is divided into five 60-ft. sections. These sections are lettered from *A* to *G* for reference.

TABLE III

COMPUTATION OF FACADE ILLUMINATION

UNITS			Illumination By	FOOT-CANDLES ILLUMINATION ON SECTION						
No. Used	Total Rated Lumens	On Section		A	B	C	D	E	F	G
12	24,000	A	Proj.*	2.046	0.428					
			Direct†			0.276	0.144	0.072	0.036	0.024
6	12,000	B	Proj.	0.172	1.200	0.176				
			Direct				0.072	0.036	0.018	0.012
18	36,000	G	Proj.						1.066	2.132
			Direct	0.054	0.144	0.414	0.216	0.108		
8	16,000	F	Proj.					0.712	1.424	0.238
			Direct	0.024	0.064	0.184	0.096			
8	16,000	E	Proj.				0.950	1.424		
			Direct	0.024	0.064	0.184			0.024	0.016
4	8,000	D	Proj.			0.480	0.594			
			Direct	0.012	0.032			0.024	0.012	0.008
2	6,000	C	Proj.		0.228	0.740	0.246			
			Direct	0.006				0.012	0.006	0.004
58	118.000			2.338	2.160	2.454	2.318	2.388	2.586	2.434

*Proj. = Projected Light. †Direct = Direct Light.

SUMMARY OF TABLE III

Average illumination from beams	2.00 ft-cd.
Average illumination from direct light	0.38 ft-cd.
Average illumination from beams and direct light	2.38 ft-cd.
Average illumination from rated lumens	2.47 ft-cd.

The summary of Table III shows how important is the direct light, which amounts in this case to 19 per cent of the beam light and almost compensates for the light lost at the ends of the building.

Facade Lighting as Computed by the Chart Method

In giving an example of facade lighting the purpose is to illustrate the use of the chart and not particularly to show a model example of illumination. To bring out some of the peculiar problems encountered let us take rather an extreme case of large areas, high angles of incidence and low average illumination. Let us assume that the building of Fig. 43 is to be illuminated on two facades from a single lighting station at the point of sight, and that an average illumination of 2.5 ft-cd. will be sufficient.

The *first* step in making the lighting plan is to draw the outline of the building on the spherical projection chart, using the lighting station as the point of view. Each facade is divided into a number of vertical sections, so that the drawing will indicate the areas

The *second* step is to compute the illumination from a single bare lamp along a line through the centers of these sections. This is done because there is a quantity of light radiated directly from the lamp that will illuminate the building, and this light is particularly useful on account of its perfect freedom from images, such as are found in the projected beam. In the units to be employed, a 500-watt lamp is used and the direct light from the lamp may be taken as 500 candles. This makes a generous allowance for losses in the door of the floodlight and for possible interference due to crowding of the units.

On the basis of 500 candles per unit the illumination in the centers of the sections from *A* to *G* are, in foot-candles, 0.003, 0.008, 0.023, 0.012, 0.006, 0.003, and 0.002. These values may seem small but if each illumination is multiplied by the number of lamps they will in the aggregate amount to a considerable fraction of the whole illumination.

The *third* step is to begin on the more distant sections and assign to each a number of beams that will bring the illumination nearly up to the desired level. Thus 12 beams applied to section *A* (four to each circle in the illustration) with an estimated covering efficiency of 0.6 will give this section 14,400 lumens, which distributed over the 7040 sq. ft. of the panel will give an illumination of 2.046 ft-cd.; and the section of the beams that overlap onto section *B* will give an average of 0.428 ft-cd. The covering efficiency is estimated from the fraction of the beam section that falls within the bounds of section *A*, making allowance for the greater intensity of light in the center of the beam. These values are given on the first line of Table III. On the second line is given the direct light falling on the other sections from *C* to *G*. It will be noted that section *C* receives over a quarter of a foot-candle of direct light from units that do not bear directly upon it. All the beams on section *A* are at maximum concentration of 11 deg. total width, and even then there is a considerable loss of light above and to the side of the section.

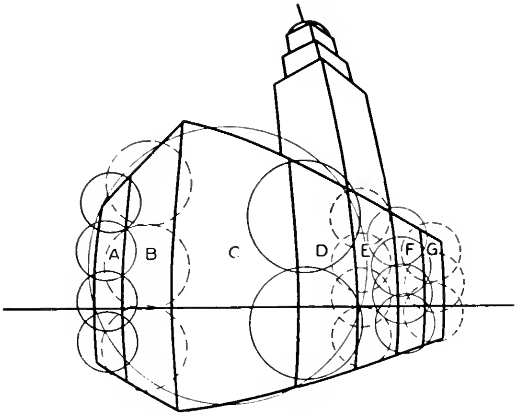

Fig. 43. The Building of Fig. 41 Redrawn in Spherical Projection. The circles on Sections *A*, *E*, *F*, and *G* represent areas covered by 11-deg. beams; the circles on Section *D* are for beams from the same type of unit spread to maximum diameter; while those on Section *B* have an intermediate size. The large circle centered on Section *C* is from a different type of floodlight giving an extremely wide beam. The computation of facade illumination by the spherical projection method requires the simultaneous preparation of a drawing of this character and a table of values such as given in Table III

The *fourth* step is to assign beams to section *B*, which in spherical projection is seen to be of double the angular area. It would seem wise in this case to spread the beams to about 15 deg. and thus take advantage of the greater softness of outline.

Step *five* is to illuminate section *G* at the opposite end of the building with 18 beams of 11-deg. width and a covering efficiency of 0.4.

Step *six* is to assign eight concentrated beams in section *F*, and adding to each column of Table III the proper amount of beam and direct light.

Step *seven* is to assign eight beams to section *E*, keeping the beams well in toward the near side of the section so that *E* will not receive too much light. This precaution is called for because a summation of the light already tabulated shows section *E* to have an average of 0.9 ft-cd. and most of this illumination is on the far side.

Step *eight* is to direct four spread beams onto the near ends of section *D*, as this section is also unequally illuminated by light from the beams on section *E*.

Step *nine* is to direct two beams from another type of floodlight onto section *C*. This section had received nearly two foot-candles from units bearing on the other sections, and the small amount of additional light could not be properly distributed with the floodlight used on the previous sections. These wide angle reflectors give 3000 lumens with the same lamp, as will be noted from the rated lumens given in the tabulation.

Sign Lighting Computed by the Chart Method

It is sometimes difficult to plan illumination for surfaces that are irregular or broken in outline, particularly if of large area and a number of lighting units are required. For this type of work the spherical projection chart is a great help as it removes any doubt that may exist as to the angular dimension of the surface. Recently, recommendations were made for the illumination of a sign, Fig. 44, made up of three capital letters, each 56 ft. high and 8 ft. across each section of the letter. The total area is about 6000 sq. ft. and preliminary experimental work by the designing engineers has shown that from 10 to 15 foot-candles would be most satisfactory. The three letters of the sign stand close to one another; but as each letter in Figs. 45 and 46 is drawn in spherical projection as seen from a different point of view, they are shown separated in the latter illustrations.

The letter *F*, drawn in spherical projection, as in Fig. 45, showed that with the beam of the selected floodlight drawn down to the narrowest angle the loss of light around the edges of the letter would be over two-thirds of the total light. Without the chart it would have been a matter of some difficulty to have computed the approximate average illumination.

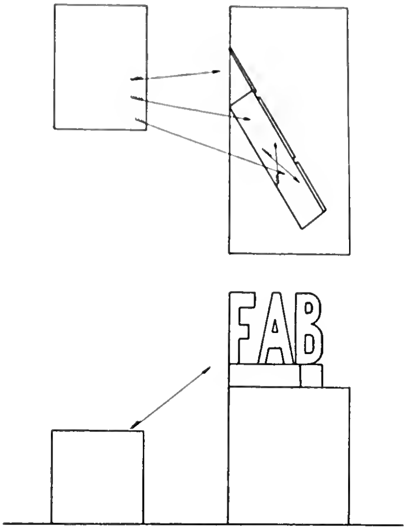

Fig. 44. Plan and Elevation of Two Buildings on One of Which is Mounted an Advertising Sign with Letters 56 Ft. High Floodlighted from Stations at the Base of the Sign and on the Top of the Other Building

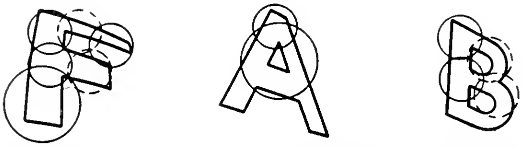

Fig. 45. Spherical Projection of the Letters as Viewed and Lighted from the Stations on the Building Top Across the Street

There were two locations available for locating the lighting units, one across the street from which the entire sign except the lower part of the *A* and *B* could be reached, and a station close to the foot of these letters for the remaining section. The *A* and *B* as seen from the edge of the supporting frame are shown in Fig. 46, where each letter is viewed from a station as indicated by the arrows in Fig. 44. In the recommendations three sizes of beam from the same unit were called for, as it was found that neither the concentrated nor the fully spread beam would be suitable in all cases.

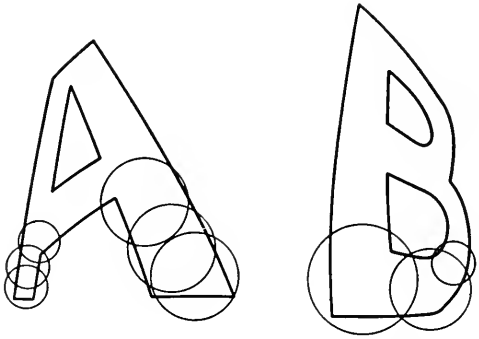

Fig. 46. Spherical Projection of the Letters *A* and *B* as Viewed and Lighted from the Stations at the Base of the Sign

The covering efficiency for the entire sign is estimated to be less than 70 per cent, that is 30 per cent of the light is lost around the sides of the letters.

The floodlights on the supporting frame were directed at the letters at a large angle of incidence so as to spread the beams out to cover larger areas, and even with this help some of the lights had to be thrown out of focus to the maximum degree, as illustrated by the larger circles on the foot of the letters *A* and *B*, Fig. 46.

(*To be continued*)

PREVIOUS INSTALLMENTS OF THIS SERIES OF ARTICLES

PART I. Types of Light Sources and Analysis of Paraboloidal Reflecting Surface by Meridian and Sagittal Lines (*February, 1923, p. 75*).

PART II. Parabolic Cylinder and Ellipsoidal Reflectors (*March, 1923, p. 160*).

PARTS III and IV. Characteristics of a Parabolic Mirror and Spherical Source of Light (*April and May, 1923, pp. 230 and 280*).

The Probable Number of Stops Made by An Elevator

By Bassett Jones

Consulting Engineer, New York City

It is always hard to determine the number of elevators required to give satisfactory service in large buildings. It is also hard to determine the duty cycle of the motor. The number of elevators required, and the duty cycle of the motors, are functions of the number of stops. The author applies the theory of probabilities to determine the probable number of stops.—Editor.

General

In determining the number of passenger elevators required in a building, and in determining the arrangement of these elevators in banks, or groups of cars serving different groups of floors, the rational method is to treat the problem as one of traffic handling on the basis that "the passenger is the standard automotive package that stacks itself in one tier."

Let P be the total number of passengers arriving on the ground floor in the period Q. The value of P may be determined either from a definite knowledge of the total population and their working schedules, or, such definite knowledge lacking, from a more general knowledge of population densities in various types of buildings used for various purposes, and from the corresponding records of traffic flow.

One phase of the subject, called the problem of arrival traffic, is concerned with moving the P passengers from the ground floor in the time Q, and for this purpose, to use the most economical number and best arrangement of elevators coupled with service of suitable character.

The round trip time of each elevator having a given time-velocity characteristic is determined by the distance it must travel, the number of passengers it carries and the number of stops it must make. The first two elements are direct functions of the arrangement of the building and of the interval or time between departures.

Generally the interval is determined by the service required. It sets the available loading time, and therefore the maximum number of passengers that the car will be required to carry and, so, the rated car load and its size.

The *round trip time* is the time between the moment a car leaves the ground floor until, having completed its trip, the car again reaches the ground floor, waits at the ground floor during the interval time, and the moment it leaves on the next succeeding trip. The round trip time is composed of (1) *running time*, or the total time the car is normally in motion between stops and is a direct function of the velocity-time data for the type of equipment adopted, (2) *standing time*, or the total time the car is standing at floors including the interval, and (3) *lost time*, or the time consumed by false stops if any, the time consumed by limit slowdowns, and the synchronizing time, or the time allowed for maintaining the schedule when an abnormal number of stops occur, or for other reasons. Each of these must be separately computed, for each depends on a different set of factors, although all three are a function of the number of stops made.

Dividing the round trip time by the interval gives the number of cars required to maintain the schedule of operation, and to handle the traffic.

Object

The object of this article is to explain a method based on the theory of probabilities, for determining the number of stops. The method of probabilities is merely the only known intelligent method of guessing. The only criterion of its legitimacy is the test of experience, and in this regard, it has proved to be quite satisfactory.

The application of the theory of probabilities to any class of data requires that, to a certain degree, the data be of random events.* In the case of elevator operation the assumption is that in all buildings the ordinary

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*In a previous article published in the General Electric Review, Vol. XXV, No. 7, p. 405, the writer assumed that in a very wide class of motor-drives, the starting and stopping of all the motors in a group could be considered as random events, and that the theory of probabilities applied to such cases furnished a method for determining the average input, the r.m.s. input, and the time distribution of input to the group. An error in the necessary preliminary discussion of duty cycles led to error in the resulting group r.m.s. input, negligible in most cases. The error did not affect the legitimacy of the method, nor did it affect the average input to the group, or the time distribution of input to the group.

movement of the population, in so far as it affects the elevators, can be considered as random. This is equivalent to assuming that all floors are equally weighted. That is, that there is no antecedent reason why any one passenger should wish to get off at any one floor, or that any particular number of passengers should wish to get off at any particular floor.

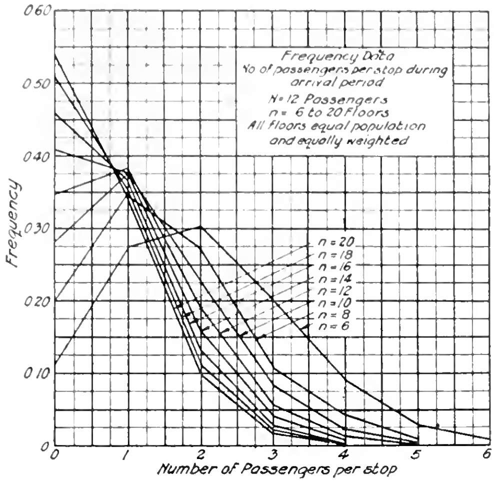

Fig. 1

Method

Assume that N passengers enter an elevator car at the ground floor, and that this car serves n floors. The question is at how many of the n floors will the car stop to discharge passengers, and what is the probable number of passengers discharged at any floor.

Each passenger has a choice of n floors. Therefore the probability that he will wish to get off at any particular floor is $1/n$. The probability that he will not so wish is $1-1/n=\frac{n-1}{n}$. The probability that all of the N passengers will wish to get off at any particular floor is $\left(\frac{1}{n}\right)^N$. The probability that none of them will so wish is $\left(\frac{n-1}{n}\right)^N$.

In general, the expansion of the point binomial

$$\left(\frac{n-1}{n}+\frac{1}{n}\right)^N=\left(\frac{n-1}{n}\right)^N+N\left(\frac{n-1}{n}\right)^{N-1}\cdot\frac{1}{n}+\ldots+{}^N C_r\left(\frac{n-1}{n}\right)^{N-r}\left(\frac{1}{n}\right)^r+\ldots+\left(\frac{1}{n}\right)^N. \quad (1)$$

gives:

1st term: The probability that none of the passengers will wish to get off at any one floor.

2nd term: The probability that one passenger will wish to get off at any one floor, and that the remaining $(N-1)$ passengers will not so wish.

$(r+1)^{th}$ term: The probability that r passengers will wish to get off at any one floor and that the remaining $(N-r)$ passengers will not so wish.

$(N+1)^{th}$ term: The probability that all the N passengers will wish to get off at any one floor.

The values of the terms in this expansion for a few usual values of N and n are shown graphically in Figs. 1 and 2. Since frequency of occurrence is synonymous with probability, these graphs may be looked upon as representing the probable frequency with which any number of passengers will leave the car at any stop, also as showing the probable distribution of the N passengers among the total number of stops made.

This statement results from the assumption that N, which corresponds to the number of trials is sufficiently large. In any particular case of elevatoring we are not so much concerned with individual round trips of a single car as with all the round trips made by all the cars in a bank during a given traffic period. In other words we are primarily concerned with the mean round trip for the whole bank. Thus, the terms in (1) may be taken to represent the mean conditions for several cars each making two or more round trips. In the usual high class office building case the upper quartile of the arrival traffic distribution curve, on which the elevator equipment is based, shows that from 200 to 250 passengers will be handled by each bank during the maximum 5-minute period, involving a total of about 15 round trips.

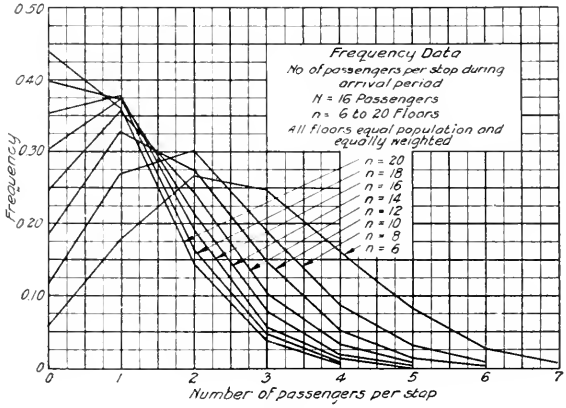

Fig. 2

From (1), the frequency with which no passengers will wish to leave the car at any of the n floors is given by the term

$$P_0 = \left(\frac{n-1}{n}\right)^N. \tag{2}$$

This term determines the probable number of floors at which the car will not stop. If S be the probable number of stops made,

$$S = n\ (1 - P_0) = n \left\{ 1 - \left(\frac{n-1}{n}\right)^N \right\}. \tag{3}$$

Values of S for various values of N and n are plotted in Fig. 3.

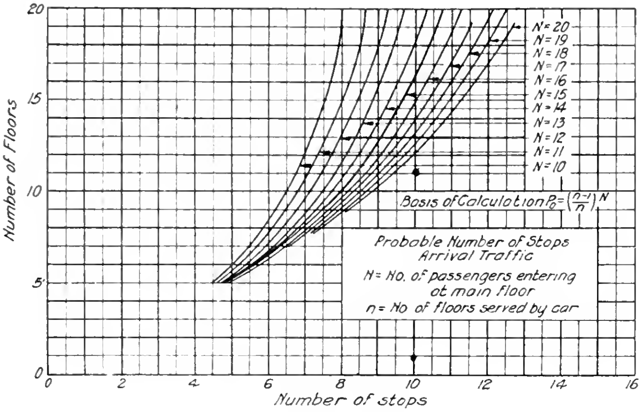

Fig. 3

The problem can be visualized readily by means of a dice analogy. For simplicity assume the usual cubical dice, but of which five faces are blank and the remaining face given some identifying mark. Let there be N dice, of $n = 6$ faces. Each dice represents a passenger. Each face of the dice represents a landing. The marked face of the dice represents the passenger's intention to get off at some one of the six landings.

If a dice be thrown, the probability that the marked face comes up is 1/6. The probability that it does not come up is 5/6. If N dice representing N passengers be thrown simultaneously the probability that any number of marked faces from zero to N come up simultaneously is given by some term, in the expansion of

$$\left\{ 5/6 + \frac{1}{6} \right\}^N$$

If a throw be made for each landing, that is, six throws of the N dice, the probable result will in each case be the same, and the relative value of each term represents the probability that the number of passengers represented by each such term will wish to leave the car at any landing. The most probable distribution of the N passengers among the six landings will be in proportion to the values of the terms in the expansion of $\{5/6 + 1/6\}^N$. Of these, the first term $(5/6)^N$ is associated with zero passengers and therefore it is proportional to the number out of the total landings at which the car will not stop. On the same scale the total number of landings is proportional to 1.0. Therefore $\{1 - (5/6)^N\}$ is proportional to the number of landings at which the car does stop. This number of landings is $6\{1 - (5/6)^N\}$, and is the value of S for this case.

For ease in obtaining numerical values the formula (1) may be written,

$$\left(\frac{n-1}{n} + \frac{1}{n}\right)^N = \frac{1}{n^N}\left\{(n-1)^N + N(n-1)^{N-1} + \ldots + {}^N C_r (n-1)^{N-r} + \ldots + 1\right\} \tag{1b}$$

The expression in the right-hand bracket is the expansion of $\{(n-1) + 1\}^N = n^N$ which is the total number of ways in which the passengers may leave the car. Eliminating the term $(n-1)^N$, which is the total number of ways in which the passengers do not leave the car, the sum of the remaining terms is $n^N - (n-1)^N$, which is the total number of ways in which the passengers actually leave the car.

The most probable number of stops, S, defined by (3) may be called the *normal stops*, and defines the *normal round trip*.

Probable Variations from Normal

But we must also determine the probable variations from the normal stops, since the net effect of such variations may be to increase the round trip time in a sufficient number of round trips to slow down the service.

Let us take a case. Assume $N = 12$, $n = 10$, then, from (2),

$$P_0 - \left(\frac{n-1}{n}\right)^N = \left\{\frac{9}{10}\right\}^{12} = 0.282,$$

and from (3),

$$S - n\left\{1 - \frac{(n-1)^N}{n}\right\} = 10 \times 0.72 = 7.2$$

or, the value of S can be obtained directly from Fig. 3.

The question then is, what is the probable frequency of round trips in which $S' = S \pm X$ stops will occur?

This question is equivalent to asking under what conditions may the first term in the expansion of $\left\{\left(\frac{n-1}{n}\right)+\frac{1}{n}\right\}^N$, or the term $\left(\frac{n-1}{n}\right)^N$, be greater or less than the value obtained when $N=12$, and $n=10$, or what is the same thing, when is $\left\{1-\left(\frac{n-1}{n}\right)^N\right\}$ less or greater than the value obtained for $N=12$, $n=10$. Obviously, when either N or n are less or greater than the values given. But n cannot change, therefore the variation must be equivalent to a decrease or to an increase in N, which is a probable cause of variation in S.

Therefore we must find the value of N which, for a fixed value of n, gives the desired change in S.

From (3)

$$N=\frac{\log\ (1-S/n)}{\log\left(\frac{n-1}{n}\right)} \tag{4}$$

Giving any value S' to S, for any given value of n, from (4) the probable value N' of N can be determined. From this the corresponding value of P_0 or P_0' can be found from (2).

The relative values of P_0 and P_0' corresponding respectively to N and N' are then measures of the relative frequency with which S and S' stops may occur and therefore, of the relative frequency of the round trips involving S stops and of the round trips involving S' stops.

The value of P_0^1 is the probability that no passengers will wish to leave the car at any floor in a round trip involving S' stops, where $S'=S \pm X$. If we put

$$P_0'/P_0=W^1, \tag{5a}$$

when $S'>S$, and

$$P_0/P_0'=w^1 \tag{5b}$$

when $S^1<S$. In either case, put

$$P_0=w, \tag{6}$$

then w is proportional to the number of normal round trips involving the normal number of stops and w^1 is proportional to the number of round trips involving $S^1=S \pm X$ stops.

The use of (4) can be avoided by using the relations given by (3), namely,

$$S=n(1-P_0),$$

and

$$S^1=n(1-P_0^1).$$

Then

$$P_0=1-S/n, \tag{7a}$$

and

$$P_0^1=1-S^1/n. \tag{7b}$$

Therefore, when

$$S^1>S,$$

$$w^1=\frac{1-S'/n}{1-S/n}=\frac{n-S^1}{n-S} \tag{8a}$$

and, when $S^1<S$,

$$w^1=\frac{n-S}{n-S'} \tag{8b}$$

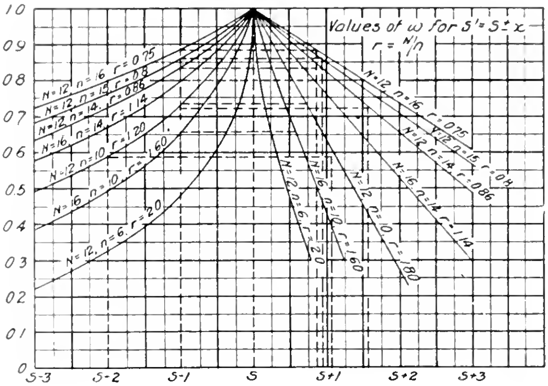

Fig. 4

If any value of N and n be given, the value of S is found from the graph in Fig. 3 and the corresponding value of P_0 from the appropriate graph in Figs. 1 and 2. Then by (8a) or (8b) the values of w^1 may be determined for $S^1=S \pm x$.

The value of w^1 for various values of N and n are shown graphically in Fig. 4. These graphs show that:

1. The probable frequency of variations from the normal round trip increases as the ratio $r=N/n$ decreases; that is, for any given number of passengers N per car, the probability of variations from the normal increases as the number of floors served, n, increases.

2. Except for a very limited range both in the value of r and in the value of x in $S^1=S \pm x$, it is more probable that the value of S^1 will be less than the normal than it will be greater than the normal. In other words, only in a few cases is it likely that any material number of round trips will occur involving a number of stops in excess of the normal. Therefore, except in a few cases, ample precautions against delay will be taken if the normal round trip time be used to determine the proper number of cars.

These conclusions also follow both from experience and from obvious general considerations. They may be summed up by saying that in nearly every case the actual average number of stops during any traffic period will be less than the most probable number of stops calculated on the basis of random traffic. The actual traffic is more likely to depart from its assumed random character in a negative direction than in a positive direction.

Having thus determined the normal number of stops, dividing the hoist by the number of stops less one, (S−1), gives the average distance the car travels start to stop, from which, and from the velocity-time data for the type of hoisting engine being considered, the normal running time can be determined with some reasonable degree of accuracy.

Non-random Arrival Traffic

If, due to unequal weighing of the floors, the traffic is not random, say, because a specially prompt arrival occurs on one group of floors, because the bank serves groups of floors having markedly different areas, or because certain groups of floors have markedly different population densities, divide the floors served by the bank into the necessary groups n_1, n_2, etc., and divide the passengers per car into proportional groups N_1, N_2, etc. Then determine the value of S for each such group, and add together the results. Such conditions will be of importance only in rare cases.

Transient Traffic

The maximum number of stops may not occur during the arrival period, but during the noon period when people are simultaneously arriving and departing. The rate of passenger flow may be less than the rate of passenger flow during the arrival period, but the cars make stops in both directions of motion. Again there may be some departure traffic during the maximum arrival traffic; all of which depends on the working habits of the population.

This simultaneous arrival and departure traffic during the noon hour or at other periods may be called "transient traffic." In such cases, let N_1 be the number of passengers entering the car at the ground floor, and let N_2 be the number of passengers leaving the car on its arrival at the ground floor. Then S_1 is determined as the most probable number of stops on the up motion, and S_2 is determined as the most probable number of stops on the down motion. Their sum is the most probable number of stops in the round trip.

Comparison with Experience

For a long period it has been the custom, based on observed stops, to assume that during the morning arrival traffic peak the cars would stop at 0.8 of the floors on the up motion while delivering the passengers loaded on the ground floor. It is interesting to note how much of the data presented in Fig. 3, averages $S = 0.8\ n$. This figure will approximate to a very large range of usual cases. Purely arbitrary allowances have been made for an abnormal number of stops, which allowances experience has proved were as likely to be insufficient as to be too liberal. In such cases the wrong value of S was used. As shown above, if the proper value of normal stops, S, be used, ordinarily no such allowance will be necessary.

A comparison of the computed number of stops with the actual number of stops was recently made in four large office buildings. The average number of passengers both entering and leaving the cars at the ground floor and the average number of stops made by the cars during the arrival period were determined by count. The data as to number of passengers and number of floors served was taken into the curves of Fig. 3. The results varied from the count by tenths of a stop. In one case the variation amounted to somewhat over one stop.

Furthermore, it has been a very general custom to estimate the number of elevators of some arbitrary size required on the basis of some entirely empirical ratio to total rentable floor area. The above discussion shows why such a method is likely to give wrong results unless the ratios compared are from identical buildings used for identical purposes and occupied by the same class of tenancy. So far as the method discussed above is concerned, the rentable area enters in only when other and more accurate determinations of population are not available.

Application to the Determination of Power Input

Having thus determined the probable average, or normal number of stops, and their time distribution, an average duty cycle can be set up and the probable time distribution of input to the hoisting engines established by the method given in "Resultant Duty Cycles," GENERAL ELECTRIC REVIEW, Vol. XXV, No. 7, p. 405 (see footnote page 583).

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alloys, Magnetic
Magnet Steels. Kayser, J. Ferdinand.
Elec'n, May 25, 1923; v. 90, pp. 557-558.

Alternators
Three-Phase Generators for Direct Coupling to Water Turbines. Lewinnek, Georg. (In German.)
AEG Mit., Apr., 1923; v. 19, pp. 121-132.
(Compares older and newer types; discusses strength calculations, assembly of horizontal and vertical types, cooling methods, etc.)

Arc Welding
Electric Arc Welding. Mattice, Royal.
Engrs. and Engng., Apr., 1923; v. 40, pp. 91-98.

Bearings
Power Lost in Shaft Bearings. Brayton, H. M.
Am. Mach., June 14, 1923; v. 58, pp. 861-863.
(Includes equations and chart for determining power losses).

Blowers
Why Fans Often Cease to Give Satisfaction and Frequently Take Excessive Power to Drive. Robinson, J. R.
Coal Age, May 31, 1923; v. 23, pp. 891-894.
(From a paper before the Engineers Society of Western Pennsylvania. Pertains to fans for mine ventilation.)

Cars, Electric
Pittsburgh's New "Light Six" Train.
Elec. Rwy. Jour., June 2, 1923; v. 61, pp. 919-922.
(Illustrated description of the electrical equipment of trolley car and its motorized trailer.)

Circuit Breakers
Dimensioning, Construction and Rating of Oil Circuit Breakers. Charpentier, P. (In French.)
Revue Gén. de l'Elec., May 5, 1923; v. 13, pp. 737-745.
(Expounds various design theories and shows test data which seem to support them.)

High-Speed Circuit Breakers, and Protection Against Arcing at the Commutators of Electrical Machinery. Candie, V. (In French.)
Revue Gén. de l'Elec., May 19, 1923; v. 13, pp. 826-828.
(Supplements an article of the same title in the May 20, 1922 issue, pp. 743-752.)

Electric Controllers
Operation of Gearless Traction Elevator Controller. Zepernick, Wm.
Power, June 5, 1923; v. 57, pp. 886-892.

Electric Cables
Permissible Current Loading of British Standard Impregnated Paper-Insulated Electric Cables. Second Report on the Research on the Heating of Buried Cables.
I. E. E. Jour., May, 1923; v. 61, pp. 517-593.
(Extensive report of the British Electrical and Allied Industries Research Association. Serial.)

Electric Current Rectifiers
Connecting and Disconnecting Mercury Vapor Glass-Tube Rectifiers. Rothenberger, A. (In German.)
Siemens-Zeit., May, 1923; v. 3, pp. 234-238.
(Discussion of switching operations on parallel-connected rectifiers.)

Electric Drive—Blowers
Brown-Boveri Electric Blowers for Scavenging the Cylinders of Two-Cycle Diesel-Sulzer Engines. (In French.)
Génie Civil, May 26, 1923; v. 82, p. 501.
(Brief description.)

Electric Drive—Paper Mills
Possibilities of Electrification in the Pulp and Paper Industry. Rogers, H. W.
N. E. L. A. Bul., June, 1923; v. 10, pp. 333-336.
(General summary.)

Electric Drive—Steel Mills
Economic Principles Governing the Use of Electrical Power in Iron and Steel Works. Ablett, C. A.
Elec'n, May 18, 1923; v. 90, pp. 530-531.
(Abstract of a paper before the Iron and Steel Institute.)

Electric Mill Drive is Efficient. Davis, Henry E.
Iron Tr., May 31, 1923; v. 72, pp. 1611-1614.
(From a paper before the American Iron and Steel Institute. Describes the equipment of an electrically-driven merchant bar mill.)

Electric Furnaces
Refractory Requirement Rigid. Williams, Clyde E.
Foundry, June 1, 1923; v. 51, pp. 433-435.
(Discusses the requirements for more suitable linings for electric furnaces.)

Theory of High-Frequency Induction Furnaces. (In French.)
Revue Gén. de l'Elec., May 19, 1923; v. 13, pp. 820-821.
(Discusses the cases where the furnace is supplied with steady sinusoidal current and with oscillating current.)

Electric Heating, Industrial

Heating Tires Electrically for Shrinking. Mann, Francis P.
Am. Mach., June 14, 1923; v. 58, pp. 879-880.
(Illustrated description of a device developed by the Oerlikon Works, Switzerland. The work forms a short-circuited secondary of a transformer.)

Electric Locomotives

New Locomotives of the Riksgränsbahn. Wist, Engelbert. (In German.)
AEG Mit., Apr., 1923; v. 19, pp. 137-144.
(Illustrated description of locomotives for the Swedish State Railways.)

Proposition for the Electrification of Railroads. Stassano, E. (In Italian.)
Elettrotecnica, May 5, 1923; v. 10, pp. 275-279.
(Author advocates the use of electric locomotives generating their own power by means of internal combustion engines.)

Electric Ovens

Heat Treat to Remove Strains. Dwyer, Pat.
Foundry, June 1, 1923; v. 51, pp. 429-432.
(Illustrated account of electric annealing of large castings.)

Electric Transformers

Three-Phase Auto-Transformer Connections. Dahlgren, F. A.
Elec'n, June 8, 1923; v. 90, pp. 616-617.
("The relative advantages of possible arrangements.")

Electrical Machinery, D-C.

Contribution to the Geometry of D-C. Machines. Ollendorff, F. (In German.)
Elek. Zeit., May 10, 1923; v. 44, pp. 425-428.
(Shows how the load characteristics for shunt, series, and compound generators can be developed from the no-load characteristics. Calculated results check well with actual test data.)

Engineering

Professional Status of Engineering. Harrington, John Lyle.
Engrs. & Engng., Apr., 1923; v. 40, pp. 99-102.
(Author is President, A.S.M.E.)

Ethics

Principles of Good Professional Conduct for Engineers.
Engng. News-Rec., May 24, 1923; v. 90, pp. 915-916.
(Rules adopted by the American Association of Engineers.)

Gears

Modern Industrial Gear. Phillips, W. H., and Burnham, L. F.
Engrs. Soc. W. Pa. Proc., Feb., 1923; v. 39, pp. 19-43.
(Fundamentals of gear design and manufacture.)

Generators

Flickering of Incandescent Lamps as a Function of the Coefficient of Stability of the Generator. Hein, J. (In German.)
AEG Mit., Apr., 1923; v. 19, pp. 132-137.
(Discussion of the relation between flickering and generator characteristics.)

Grounds, Electric

Compensation of Accidental Grounds in Cable Installations. Pfannkuch. (In German.)
Elektro-Jour., Mar., 1923; v. 3, pp. 47-50.
(Discussion of the Peterson coil as applied to underground cables. Concludes that it is even better adapted for such work than for overhead lines.)

Hydroelectric Development

Ritom Power Plant of the Swiss Federal Railways. Eggenberger, H. (In German.)
Schweiz. Bau., May 19, 1923; v. 81, pp. 246-249.
(Illustrated description. Serial.)

Interchangeable Manufacture

Interchangeable Manufacture Applied to the Construction of Electrical Machinery. Drescher, C. W. (In German.)
Elek. Zeit., May 3, 1923; v. 44, pp. 401-410.
(Discusses its present status in Germany.)

Laboratories

Porcelain Testing Laboratory of the Canadian Haviland Insulator Factory, Limoges, France. Crussard, P. (In French.)
Revue Gén. de l'Elec., May 5, 1923; v. 13, pp. 745-750.
(Illustrated description of a laboratory equipped for making tests up to 250,000 volts.)

Measuring Instruments

Electric CO_2 Recorders. Moeller, Max. (In German.)
Siemens-Zeit., May, 1923; v. 3, pp. 226-233.
(Discussion of how to determine the unburned portion of flue gases, and the resultant heat losses. Description of Siemens & Halske recorders.)

Electrical Measurement of Velocities of Flow in Pipes. Houk, Ivan E.
Engng., May 25, 1923; v. 115, pp. 644-645.
(Author is City Engineer, Dayton, Ohio.)

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Some Possible Connections for Rotary and for Static Phase Converters. Sachs, K. (In German.)
Elek. und Masch., May 20, 1923; v. 41, pp. 293-299.
(Discusses different connections suitable for phase conversion on locomotives.)

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Approximate Integration of Reactive Power in Three-Phase Circuits. Stubbings, G. W.
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Phase Compensation in Industrial Electric Networks. Dardenne, J. (In French.)
Revue Gén. de l'Elec., May 12, 1923; v. 13, pp. 781-786.
(Determination of optimum power-factor when synchronous condensers are used.)

Power Factor in Industrial Plant Operation. Schüler, L. (In German.)
Zeit. des Ver. Deut. Ing., May 19, 1923; v. 67, pp. 495-497.
(Discusses causes and effects of low-power factor and its remedies. Describes a new synchronous motor for power-factor correction.)

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Some Experiments in Continuous Wave Transmission. Machanik, P.
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(Paper before the Radio Society of Great Britain. Serial.)

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German-American Radio Communication. Thurn. (In German.)
Elektro-Jour., Mar., 1923; v. 3, pp. 50-55.
(Illustrated description of the Nauen and Eilvese stations, Germany, and the Rocky Point station on Long Island.)

Radiodynamics

New System of Radio Control. Webbe, H. W.
Radio News, July, 1923; v. 5, pp. 20-21, 94-96.
(Describes a system which employs the principle of sympathetic vibration.)

Radio Stathmometer. Hammond, Jr., John Hays.
Radio News, July, 1923; v. 5, pp. 12-13.
(Short popular account of radio devices for the control of torpedoes, etc.)

Radioelectric Transmission of Energy. LeBlanc, Maurice. (In French.)
Radioeléctricité, June 1, 1923; v. 4, pp. 181-184.
(Describes methods for operation of trains and automobiles by means of short waves.)

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Financial Prospects of Railway Electrification. Dawson, Philip.
Elec. Rev. (Lond.), May 25, 1923; v. 92, pp. 837-838.
(Abstract of paper before the Institute of Transport. Results of an economic investigation of a British main-line electrification. Serial.)

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Elec'n, June 1, 1923; v. 90, pp. 593-594.
(Abstract of paper by T. Grime before the N.E. Coast Inst. of Engineers and Shipbuilders.)

Ship Propulsion, Electric

Electric Drive on Battleships. Charlton, Alexander Mark.
Am. Soc. Nav. Engrs. Jour., May, 1923; v. 35, pp. 253-328.
("Simple explanation of the systems of electric drive . . . together with a discussion of the principles of the induction motor.")

Simplified Manufacture

American Engineering Standards Committee Reports One Thousand Simplification Opportunities.
Am. Mach., May 31, 1923; v. 58, pp. 805-806.
(Lists many kinds of products in which simplification of types might be effected. Includes a few instances in the electrical industry.)

Steam

Supersaturation Limit. Martin, H. M.
Engng., May 18, 1923; v. 115, p. 607.
(Short article on the theory of supersaturated steam.)

Steam Plants

Some Unusual Steam Plants in Tuscany. Hahn, Emanuel.
Power, June 5, 1923; v. 57, pp. 882-885.
(Describes natural steam and lignite utilization in Italian power plants.)

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Extracting Steam from the Turbine for Heating the Feed Water. Smits, J. J. L. (In Dutch.)
Sterkstroom, May 9, 1923; v. 1, pp. 171-177.
(Discusses the thermal efficiency attainable by using steam from the main turbine.)

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Steam-Turbine Governors and Valve Gears—Characteristics of Hunting. Thompson, Eustis H.
Power, June 5, 1923; v. 57, pp. 898-901.

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U. S. S. *Asheville.* Donald, H. G.
Am. Soc. Nav. Engrs. Jour., May, 1923; v. 35, pp. 219-252.
(Illustrated description of the vessel and of official trials. Single-reduction, mechanical-geared, Parsons type turbines are used.)

Steel—Electrometallurgy

Current Practice of Making Electric Steel. Stoughton, Bradley.
Chem. & Met. Engng., June 4, 1923; v. 28, pp. 983-986.

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Distant-Controlled, Non-Overloadable, Semi-Automatic Substation.
Elec. Rwy. Jour., May 26, 1923; v. 61, pp. 873-878.
(Illustrated description of a New York Central substation near the Grand Central Terminal, New York.)

Vacuum Tubes

Water-Cooled Thermionic Tubes for High Powers. Housekeeper, W. G.
Tech. Engng. News, June, 1923; v. 4, pp. 89, 106.
(Short account of construction and operating characteristics.)

Voltage Regulators

Application of Automatic Regulators to Train Lighting. Sylvestre, V. (In French.)
Houille Blanche, Mar.-Apr., 1923; v. 22, pp. 66-69.
(Illustrated description of the B. B. C. train lighting system.)

X-Rays

Modern X-Ray Generator. Saget. (In French.)
Soc. Fr. des Elec. Bul., Feb., 1923; v. 3, pp. 43-54.
(Illustrated description of apparatus for producing X-rays by the use of two kenetrons supplying 10 milliamperes at 250,000 volts to a Coolidge tube.)

GENERAL ELECTRIC REVIEW

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Vol. XXVI, No. 9 SEPTEMBER, 1923

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FRANKLIN S. TERRY

Vice-President General Electric Company

At a meeting of the Board of Directors on June 22, 1923, Mr. Terry, who has been prominently connected with the Incandescent Lamp business of the Company for many years, was elected a Vice-President

GENERAL ELECTRIC REVIEW

THEORY AND PRACTICE IN THE PROJECTION OF LIGHT

One of the pet phrases of technical literature is "reducing theory to practice," the implication being that theory is upon an elevated plane and requires considerable reducing to bring it down to the level of its humble co-partner. There are cases where theory is indeed greatly superior to practice, but this is not always so. It more often happens that greater intelligence and skill are required to make a thing than to theorize about it. This is largely due to the common fault theories have of being incomplete, and when we attempt to complete them we encounter the other difficult task of "reducing practice to theory."

Something along this line has occurred in the science and practice of projecting light. The theoretical optician, with perhaps more than a touch of smug content, looked down upon the struggles of the practical worker and did not realize that practice was well in advance of theory and was indeed being hindered by the lagging member of the team. If a reason is sought for this state of affairs we need look no farther than that beautiful mathematical concept known as the "point source" of light. Its beauty is its curse; and so long as the theory of projection concerned itself with only this concept, it arrived nowhere. Once the idea of a finite light source is introduced the subject immediately becomes complicated—and neglected. The practical experimenter not being aware of the troubles he is breeding for the mathematician goes ahead on a trial and error basis and, while the errors make almost the same sad total as the trials, still he makes progress and arrives at results.

Why does a high-intensity arc give five times the beam intensity with only half again the light of a low-intensity arc? Can a mirror be formed so as to concentrate light on a distant point? How wide is the beam for a 60-in. mirror at five miles? Why should a monoplane filament be used with a shallow mirror and a spherical shaped filament with a deep one? Should a large mirror be more accurately formed than a small one? Has the depth of the crater any influence upon the choice of mirror angle?

These are samples of practical and important questions on which the literature of the subject is almost silent, for the classical "point source" of the text books sheds very little light that is of direct service to the experimenter, and if he has often stumbled the blame is not entirely his.

Beginning with our February issue we printed the first of a series of articles on "Studies in the Projection of Light" in which the author has outlined the theory of projection as applied to light sources in everyday service. Mr. Benford has had years of experience in designing projection equipment, but by far the greater part of his work has been in the testing of both experimental and standard devices intended for a wide variety of service. A proper test can hardly be run without some little study of the inward workings of the beam, and from these enforced studies has arisen what is probably the most complete mathematical survey of the theory of projection that has so far been published.

There are few branches of engineering that are more in the public mind or that seem to have a better future ahead than this branch of illuminating engineering. The automobile headlight alone is the subject of considerable legislation and police regulation (with a different set of laws and rules for each locality); and it does not take much of a seer to predict that when we travel in our individual airplanes we shall be in need of all the knowledge that can be gained by a most earnest co-operation of theory and practice. Today there is a battle on between the bombing plane and the defending gun aided at night by a beam of light. Victory for the defending forces depends largely upon how we combine all our resources in the design and construction of the searchlight.

Staging the Unseen

By Kolin D. Hager

Radio Broadcasting Station WGY, General Electric Company

In our April issue of this year there appeared an article which described the equipment and engineering features of operation of Radio Broadcasting Station WGY. The following article was written at our request to explain the personal phase of the station's operation. The studio management's problem has been to work out such a technique of practice as will enable a variety of worthy programs to be arranged and then broadcast with a realism which imagination makes one forget the sense of sight is not being employed as well. The ultimate aim of all this work is to evolve, from what might have been a passing fad, a real service as indispensable to the public as other standard methods of communication and entertainment.—Editor

A vast audience sits before a curtain that is never raised. Whether the program be one of education or amusement, music or dramatic art, the listening ear must be so satisfied that the unseeing eye is forgotten. Perhaps it would be more accurate to say that by sound alone the mind must be led to visualize the stage and its characters. Above the proscenium are inscribed three letters, "W G Y."

In the Studio the watchword is ever "Responsibility." The transmitting apparatus —from microphone to antenna—is merciless in the accuracy with which it spreads abroad every syllable and note exactly as they come from the lips of the speaker or singer. In fact, it registers and makes evident tonal defects that would not be perceived by one who has not had studio experience.

Here, then, is a new set of conditions that must be considered in the production of music, addresses, plays, operettas, and the many specialties that find a place on broadcast programs. On the actual stage or concert platform, where flesh-and-blood personality reaches out across the footlights, the play or song is carried over with a score of aids that make a convincing and delightful ensemble. In the broadcasting studio, however, the voice is, so to speak, dissected out of its customary surroundings and held up in cold blood for critical inspection—and even then it must suggest the warmth and verve of a performance that is visibly presented.

In its staging of the unseen, the studio management is keenly sensitive to the presence of an unseen audience. The fancy cannot help drawing a picture of unnumbered men, women, and children, gathered in circling ranks, silent, unapplauding, but critical with a concentrated attention that hardly any other form of entertainment receives. The pure force of an invisible audience, greater than any that has been assembled, impresses one with the responsibility of broadcasting far more than would the physical presence of a great assembly. Imagination? Yes; but a performance that is to appeal to the listeners' imagination must also be conceived in an imaginative spirit—and the sense of responsibility is none the less real.

There is one person, however, who must not feel an undue pressure of responsibility unless he or she be a seasoned artist whose certitude is proof against the most unusual conditions. That person is the performer. From the moment that an applicant for radio honors makes contact with the studio management, every effort is put forth to relieve the singer, or speaker, or instrumentalist—as the case may be—from any anxiety peculiar to a hidden stage and an unseen audience.

In justice to those who shall listen and in true kindness to the applicant, the first process must be one of elimination. Radio aspirants are almost as numerous as candidates for motion-picture fame. They apply by letter and in person. They are of course in quite a different class from recognized artists whose services are engaged by the Studio through established channels.

The Studio is ever hopeful of discovering hidden ability among the many who seek to put their names on its programs. The hope is not always vain. No one is refused a hearing. Whether it be a modest performer on the saxophone or a soprano who offers nothing less ambitious than "Vissi d'arte," the same courteous hearing is given.

If the voice or the instrumental ability be of such a calibre as to justify further consideration, the next step is to select numbers that will display it to the best advantage. If ever the studio directorate had need for tact it is in separating a clever amateur from some pet number that has literally been "done to death"—and the pet numbers are always the same. The weekly series of programs could be filled with vain repetitions of the "Polonaise Militaire," "Humoresque," "Melody in G," "Road to Mandalay," "May Morning," and a half dozen other "war horses" that are so universally ridden to a fall unless the rider

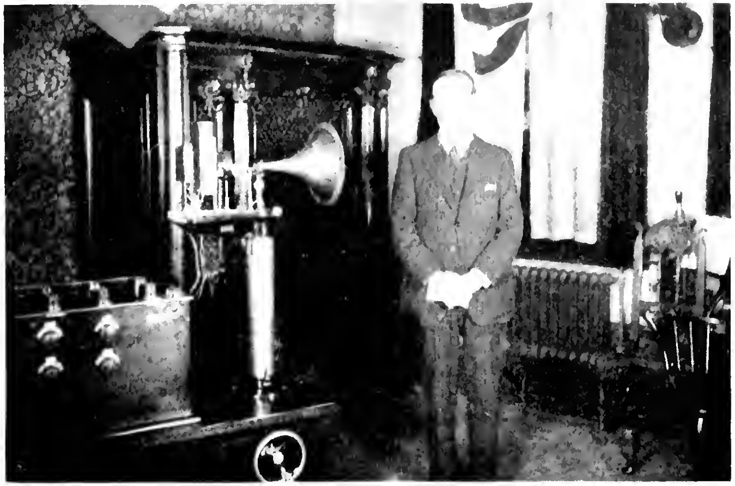


Fig. 1. Senator Guglielmo Marconi Broadcasting from WGY

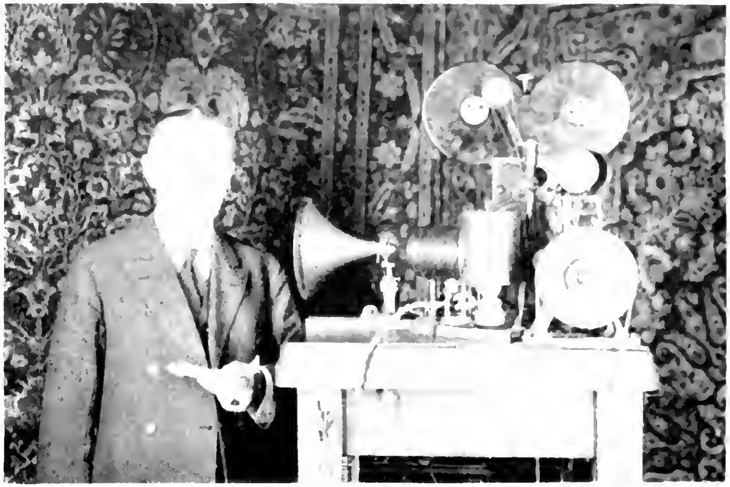


Fig. 2. President Calvin Coolidge Speaking into the Pallophotophone

Fig. 3. Nevada Vander Veer and Reed Miller, Noted Concert Artists

Fig. 4. Piano Solos from WGY Elicit Much Enthusiastic Praise

Fig. 5. The WGY Players in Action Scene from "The Great Divide"

Fig. 6. The WGY Players Discuss a New Play

Fig. 7. The Sunday Symphony Ensemble at WGY

Fig. 8. Popular Dance Music Is One of the Varied WGY Offerings

be that fine type of artist who can do simple things superlatively well.

Another problem is the vocalist who can sing a ballad well but who is convinced that the radio audience will prefer a sketchy attempt at some famous operatic aria. In the end, a selection suited to the voice and skill of the performer is suggested and insisted on with such arguments as will persuade without wounding the pride; and another item is built into a program that is being prepared for a date three or four weeks in advance.

Day by day this preliminary process goes on. Not only must the individual be carefully considered but also the nature of the whole program, the balancing of it with other and dissimilar offerings, the pleasing of every taste within the scope of a few concerts, and the observance of public holidays and national and local occasions. All of these things are variously shaped stones that must be fitted into a mosaic pattern that a critical public shall pronounce good.

The Studio has a nucleus of professional musicians, the WGY orchestra, about whose work are grouped the performers selected week by week to participate in the programs. As experienced members of the staff, the musicians in this orchestra have achieved a sense of responsibility which but adds to the artistic finish of their performance. Not so, however, with those who are making their first appearance behind the unraised curtain. Here—for we are now entering the studio proper on the evening of a performance—everything is planned to forestall the nervousness that may arise at the thought of a vast viewless audience or be evoked by the very real lonesomeness of the position.

A singer of songs, a tiny mechanism, and half a continent ready to listen! Be the voice ever so good, the music ever so well learned, there is enough of the bizarre in the situation to add an extra beat to the stoutest heart and lend a little quiver to the steadiest nerve. Facing an audience that stretches away for a thousand miles—and yet isolated! No wonder that the studio staff steps in and shifts as much as possible of the musician's responsibility to its own shoulders.

To this end, the unseen stage might well be the music room in the singer's own home. To be sure, the walls must of necessity be covered with soft fabric. The acoustics of broadcasting demand this. But the rich gray folds that hang from ceiling to floor are in themselves a home-like furnishing. There is nothing of the stage in the artistic lights or in the deep rugs that cover the floor. The comfortable chairs, the piano, and in fact all the cozy charm of the room has been planned to offset any feeling of strangeness.

Best of all, there is no uncouth instrument staring the musician in the face, ready to announce to the world any deviation from pitch or slurred pronunication. Instead there is a "homey" appearing floor lamp—at least it looks like a floor lamp—near which the performer stands. Suppose a microphone *is* concealed beneath the dainty shade; suppose it *is* our contact with a continent! It makes no impression on our minds as it falls quietly into place with its surroundings, and we shall sing and play with the same confidence as within our home walls!

There is one departure from the normal, and that adds to the interest of the experience without cramping the musician's freedom. In an adjacent control room, an unseen operator listens to every note *as it comes from the broadcasting antenna*. Under his hand are tiny switches which flash electric signals to the studio director. "Louder," "Softer," "Stand Nearer" if the singer or player needs any such instruction, the word, in letters of light, appears in sight of the director, who holds out a card, similarly inscribed, within the performer's vision. It does not disconcert; rather it is an assurance of friendly co-operation.

Thus from the first interview with an applicant to the moment when his last note rings true in a hundred thousand receiving sets, the Studio has felt and honored the responsibility with which it was charged.

So much for the initiation of one candidate into the Unseen Order of Radio Performers. The next degree is marked by more elaborate work. Would the brilliant Gilbert and Sullivan have countenanced an invisible presentation of "The Mikado," or "Pinafore," or "The Pirates of Penzance"? We entertain the opinion that they would, if they could have been present at a WGY rendering of these immortal creations.

It is all there—thanks to two microphones, a careful stage director, and an alert company of singers. The orchestra remains at one strategic point—but the caste! Such silent comings and goings as were never in the original instructions of W. S. Gilbert! Such stealthy approach to a microphone for the purpose of a solo! Such forming and dissolving of ensemble groups at another microphone! Preliminary explanations are made by the announcer, but it is in the hands of the performers to thrust the rollick and glow of the comic opera deep into the imagination of the audience.

Those who have heard these radio renditions assure us that they not only hear the stamp of the foot, they can actually see the flashing eyes and doubled fists as the Pinafore chorus bursts into the sublime swagger of "A British Tar." They can follow every grimace of the dejected Ko-Ko as he groans over the "caricature of a face" and they itch to join the dance of the "maidens from the shipping" whose steps they can fairly see through the unraised curtain.

The Studio has taken another step forward in its staging of the unseen. It is the father of the Radio Drama. Through its lowered curtain was projected the first entire play ever broadcast. It was a bold venture. Could a three-act play be *acted* by radio? The venture was made, and radio drama has become one of the Studio's most popular offerings.

Comedies of the better class are alternated with dramatic presentations, and are equally well received. One night each week is given up to the play. The orchestra is in attendance for overture, entr'acte, and incidental music, and of course the announcer performs the function of an annotated program.

The listener hears more than voices. Telphone bells ring, doors slam, wind storms rage, rain patters, the noise of moving chairs and of revolvers is heard. From these elements and from the preliminary explanations of the announcer, the drama is built before the eyes of the audience as well as in its ears. Nor are the actors to be classed as amateurs. They are men and women well seasoned in stagecraft, and with records of success in their vocation. They have brought these qualifications to the creation of a new dramatic art; they have entered into this spirit of creation with an enthusiasm and a wealth of personal resource that have uncovered remarkable possibilities in the projection of motion and scene through the medium of sound.

Not all the programs broadcast from the Studio are carried out there. It has reached across whole states and transmitted to its audience interesting public events at the very moment they occurred. Its listeners have heard from New Haven the cheering at a Harvard-Yale football game and have received word of each play as it occurred; all of this has come directly from the field. They also participated in the world's series baseball games at New York in 1922, and they have sat at distant banquet tables where famous speakers delivered messages of great import. These miracles were performed by aid of long-distance telephone wires installed at the field or in the dining hall and equipped with microphones that speeded every sound direct to the transmission apparatus of the Studio.

In so far as seriousness of purpose and effectiveness of accomplishment are concerned, WGY has struck its richest chord in the regular broadcasting of Sunday services direct from the churches in which they are held. Here, for the time, the studio abandons all suggestions of the stage and of entertainment and enters the larger room of human hearts. In a spirit of reverence and helpfulness, it takes its place among the influences that uplift men's souls as no purely cultural endeavor can.

Its mission is to the sick, the isolated, and the infirm—to all whom circumstances prevent from joining in a common worship. And yet it *is* a common worship to which they are invited. Each listener to hymn and anthem, sermon and prayer, knows and *feels* that he or she is joining hands with thousands as in spirit they kneel before one altar and unite their aspiration and devotion. Let a single letter bear evidence. It is taken from a great number of similar import and is from an aged, blind woman living on Cape Cod.

> "I am writing you a few lines this beautiful morning to tell you how much I enjoyed your good sermon Sunday afternoon, also the singing of 'Just as I Am.' The prayer went to my heart. I heard every word of the sermon and singing. I could hear just as plain as though you were in my room. I have been stone blind over 12 years, have not seen one ray of light. I take care of a crippled husband who is over 80, and cannot walk a step alone. Sometimes the way seems dark, but my dear Heavenly Father gives me strength every day. It is one of the most wonderful inventions to know that I can sit here way down on old Cap Cod, and hear such lovely sermons and singing. God bless the man that invented it!"

In different vein, but not without its own touch of pathos, is the story of a woman nearly seventy-five years old who has been unable to attend church in five years. Since the Studio began its Sunday broadcasting, this good lady dresses in her best when service time approaches, places her chair by the radio set, and attends the service. When the collection is announced, she puts her offering on a plate by her side and, next day, forwards it to the pastor of the church whose service she has heard.

In its comprehensive embrace, WGY cooperates with Government welfare agencies. The State Board of Health has broadcast a

Fig. 9. Harp Solos Prove Delightful Music for Broadcasting. "Floorlamp" microphone in foreground)

Fig. 10. Charles Wakefield Cadman, Well-known American Composer with Princess Tsianina, Mezzo-Soprano

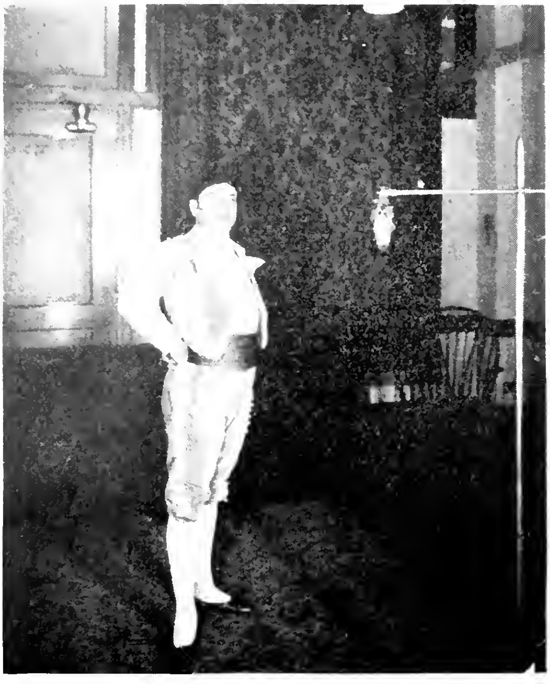


Fig 11. M. Charles Kanony, Leading Baritone of the French Grand Opera Company

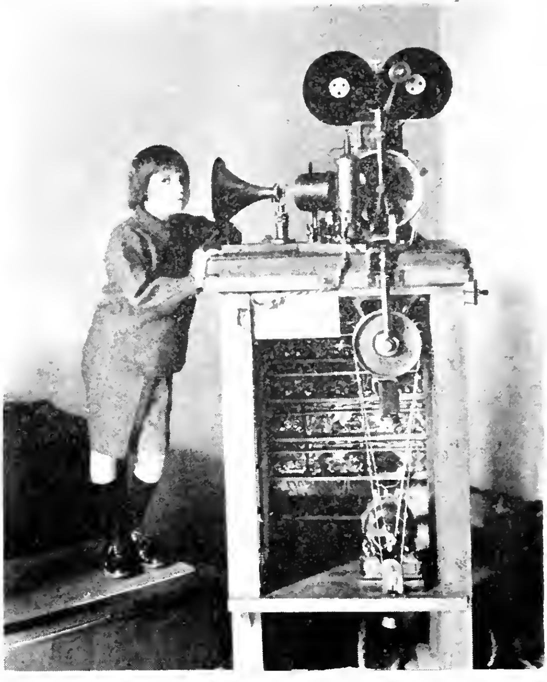


Fig. 12. Jackie Coogan Filming a Few Words for the Radio World

Fig. 13. WGY Broadcasting the Harvard-Yale Football Game from New Haven, Conn.

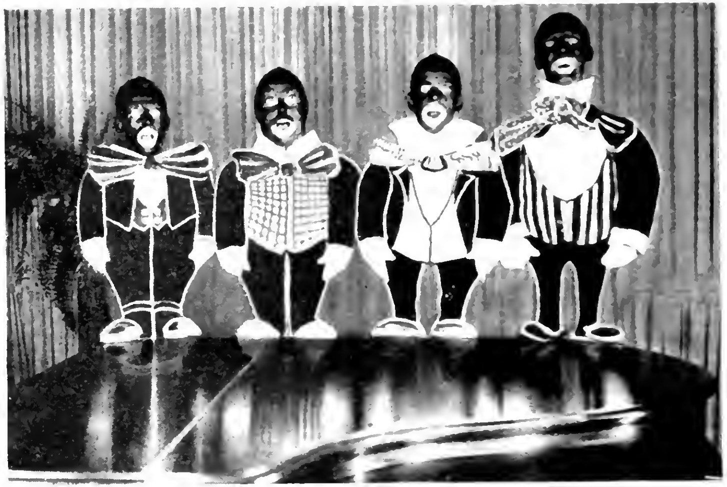


Fig 14 The Radio Four in Minstrel Garb

Fig. 15. Two Kinds of Waves Join Hands

Fig. 16. A New Outdoor Sport– Listening-in

long series of messages on the prevention of disease and on the many obscure factors that are of importance to public health. The Highway Commission gives weekly reports on the condition of New York State roads. Intimate afternoon talks are broadcast for the benefit of homekeepers who will gain by authoritative advice from experts in domestic economy. Twice a day, a complete report of the New York Stock Exchange is given, and every evening the day's produce market is reviewed for the information of growers who are engaged in sending farm and dairy products to centers of consumption.

We have spoken of the Studio's "unapplauding" audience. Let us modify the phrase. The artists who fill programs *do* receive an applause that is far more earnest than any clapping of hands. Every day, hundreds of letters are received that do not merely *congratulate* WGY on its offerings, they are also expressions of *thanks*. They chat with the studio management as with those who have entered their homes, cheered their sick and brought courage to the sorely tried. They make special mention of the melody or the word that has flown across the many miles with comfort on its wings. They ask for this or that selection as one would ask it of a friendly artist and guest. These letters are the real reward of work. They are evidences of gratitude that urge the worker to still better service—for WGY in its large aspect is a personal as well as a public service.

This article would be incomplete without reference to a special contribution which the Studio makes to general welfare—a contribution depending on its ability to speak in one breath to every town and hamlet on the continent. A man or woman has mysteriously disappeared; a child has been stolen and may have been carried far away. How can a nation be instantly put on the look-out? WGY is ready at a moment's notice to broadcast descriptions and, on occasion, offers of reward. Time and again it has performed this service, and in several instances has been the means of rescue.

This is the most dramatic scene that can be enacted in a broadcasting studio. A cry for help from those whose dear one is lost—the quick response—the turn of a switch—a few words spoken quietly into the microphone and heard wherever there is an ear to listen—a thousand communities put on the alert—and all within perhaps five minutes.

Where is there a stronger or stranger "situation" in fiction? Where is there a kindlier or more efficient service to home and public than this that is offered by the Studio?

It has been said that every man is the richer for what he gives in a spirit of good will. This truth has its expression in the broadcasting studio. More than one performer, who has shown traces of nervousness as the crucial moment approached, has been told a story of the gratitude expressed by a crippled child or an invalid whose life has been made brighter by WGY. In the interest and pathos of the story, the singer has taken on new courage. With the picture of that eager little listener before the mind's eye, a new fervor and inspiration have gone into the music—a spirit that has, in equal measure, enriched the program and the soul from whose very depths the song has come.

⁂

Electrical Development in Australasia

By G. G. Cree

Lighting Engineering Department, General Electric Company

Australia's future must in a large measure be influenced by her electrical developments. The careful study that Australian engineers have given to their engineering problems speaks well for the future. The author gives us a very interesting story from which useful lessons may be learned of Australia's electrical developments. Editor.

The traveler to Australia or New Zealand, who has not primed himself with knowledge of the "Island Continent" is likely to have a number of surprises in store for him at the end of his 10,000-mile voyage across the Pacific Ocean.

There he will find no crude civilization such as might be imagined to exist in a country that has only been settled for a matter of 100 years, and has only a population of seven million to cover an area greater than that of the United States and Great Britain combined.

The electrical development of a country's urban centers might be a misleading guide to its degree of civilization, but it would certainly provide an estimate of the progressiveness, energy and initiative of its people.

Judged on this basis Australasia ranks high. Not only is the proportion of houses reached by electric service fifth among the nations of the world, but there is now in operation in Melbourne the largest suburban railway electrification in existence, and a similar project is now under construction at Sydney.

It is probably correct to state that the people of Australia and New Zealand have more faith in the ability of electricity to solve their labor and transportation problems than any other nation, and they are backing that faith with all their resources, natural and financial.

Systems of Supply

Fifty-cycle, three-phase current has been adopted as standard except for railway work. Even in that field, the New South Wales Government Railways have decided to introduce 50-cycle turbines into their 25-cycle power house at Sydney, for the electrification of the Sydney suburban railways, so that no extensions will be made to the 25-cycle system.

Service voltages are far from uniform and an example of the onerous burden imposed on the industry is afforded by the diversity of incandescent lamp stocks. The larger importing houses must carry in stock about 600 different lamps to meet adequately the demands of the trade.

The Institution of Engineers and the Bureau of Science and Industry of the Federal Government are working actively for standardization with satisfactory results.

Practically all new alternating-current developments will distribute to consumers at 230 volts single-phase, and 400 volts three-phase, the "Y" and delta voltages, respectively, of three-phase transformers, which are commonly used.

Distribution Systems

This high service voltage is associated with a distinctive scheme of distribution. Paper insulated lead covered cables operating usually at 6600 volts are laid directly in the ground and run from the generating station or main substations to small brick transformer houses containing comparatively large distribution transformers of capacity up to 300 or even 500 kv-a. From there, the 230/400-volt supply is led to the consumer's premises. This question of distribution is one which is exercising the mind of American engineers today and there is no question of its importance.

Other nations have profited by the pioneer work of American engineers in the central station field. The consumer's voltage of 110 to 120 common to all the United States was undoubtedly chosen to meet the initial difficulties of carbon lamp manufacture. A high service voltage is a necessity in Australia where apartment houses are hardly known and practically the entire population is housed in "one-family" houses with a garden. For example, the metropolitan area of Melbourne is greater than that of New York or Paris, but the population is only 800,000.

In consequence, the distributing costs are usually greater than the generating costs. the ratio being approximately 60:40, while in comparable American utilities, it will be found that the relation between distributing and generating costs is reversed, being more nearly 40:60.

Electrical Apparatus in Australia

It is only within the last few years that Australia has turned seriously to the manufacture of her requirements in electrical equipment. In placing orders in the past, the various public utilities (they are nearly all owned by states or municipalities) have been particularly free from prejudice, and Australia has offered a market for the electrical manufacturers of all nations. As a result, competition has been keen and the visiting engineer finds there electrical apparatus of American, British, German, Swedish and Swiss manufacture, the first two, of course, predominating.

Fig. 1. Seven 3000-kw. Synchronous Converters in the Substation of the Electrolytic Zinc Company of Australasia

In operating, American and British practice is followed exclusively, the latter being particularly in evidence where the influence of British consulting engineers has been felt.

Australian engineers have not manifested any marked indication of following their lead in such details as split conductor distribution (underground and overhead) and truck type switchgear, although the latter is becoming popular in America.

The enormous size of Australia compared to its population alters the whole aspect of commerce within the country. Although Australia has more railroad mileage per inhabitant than any other country, transportation to inland points is expensive. The unfortunate adoption of different gauges by the various state railroads aggravates this condition. As a result when steam coal is, say, $5 per ton in Sydney, it will be $20 in Broken Hill, the well-known lead and silver mining center in the same state. Water in Broken Hill costs $1.25 per 1000 gallons. Naturally, the mine-owners are prepared to pay substantial premiums for high efficiency in their power equipment. It is unfortunate, under these conditions, that each mine has established its own power station. As there are ten important mines grouped closely, with a total peak load of about 20,000 kw., the conditions are ideal for central station service. It should be noted, in passing, that the generating stations of the larger mines are models of good engineering both in design and operation, while much ingenuity and originality has been exercised by the local engineers in the application of power in the mines and on the surface. To cite one example, the first application of centralized motor control on a big scale was made at "The Hill." The summers there are hot and exceedingly dusty, ambient temperatures of 115 deg. not being uncommon, so that the duty of the hundreds of motors ranging in size from ½ h.p. to 800 h.p. is unusually severe.

It is significant that General Electric equipment is used almost exclusively.

Power and Light Supply—Municipal Ownership

With very few exceptions, the retailing of electricity is in the hands of the municipal authorities. The generation of power is undertaken except where there is already in existence a nearby source owned by a larger municipality, private undertaking or the state, from which an efficient supply can be purchased.

State Control and Ownership

Until recent years the State Governments took little part in the electrical development of the country. Each state had its "Electric Light Act" which regulated the industry in a small degree, chiefly from the standpoint of safety to the public. Today, however, all the state bodies in Australasia are engaged to some degree in the business of electrical supply. The picturesque island state of Tasmania has received a remarkable amount of publicity as a result of the vigorous policy of the Government in developing the hydroelectric resources of the state. As a result, a number of industries have been attracted to Tasmania, which for many years had seemed to have reached almost its complete development as an agricultural, and later, as a mining state.

At the Waddamanna power station, there are seven 7050-kv-a. General Electric alternators driven by Boving impulse wheels under a head of 1000 feet. The voltage is stepped up to 88,000 and transmitted 80 miles to Hobart.

In this, the capital city, an historic and beautifully situated town of 60,000 inhabitants, the entire station output is absorbed.

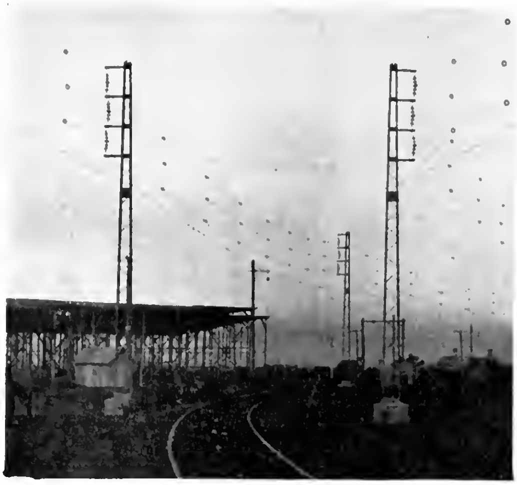


Fig. 2. Split Conductor Transmission Line, Victorian Railways. Each circuit is composed of six $\frac{7}{16}$-in. copper conductors

The largest customer of the Government is the Electrolytic Zinc Company with a capacity of over 120 tons of zinc per day. At these works, the complete electrical equipment was supplied by the Australian General Electric Company and consists of seven 3000-kw. synchronous converters by the British Thomson-Houston Company. The d-c. voltage is induction regulator controlled between 500 and 600 volts.

The switchgear was also built by the British Company, while the transformers are of General Electric manufacture.

The Victorian State Government has for years maintained a very progressive attitude toward electrical development. The electrification of the Melbourne suburban railway lines is the largest undertaking of its kind and provides the suburban dweller with transportation facilities which are not approached by any other metropolis. The possibilities of electrification were first brought to the attention of the Victorian Railway Commissioners in 1896 by Mr. A. W. Jones who was then the representative in Australia of the General Electric Company.

It was not until 1912 that contracts were placed and, after serious delays due to the war, operation was begun in 1919.

Electrification from an overhead trolley at 1500 volts has been applied to 335 single track miles. The system was described in detail in the GENERAL ELECTRIC REVIEW for August, 1920. Some of the features of the power plant equipment are of particular interest.

There are six generating units totaling 70,000 kw. in capacity. Each alternator is permanently connected to its transformer bank and differential relay protection is provided across the combined alternator-transformer unit.

The generator voltage is 3300, the distribution voltage 20,000, and the frequency 25 cycles. The main point of interest is probably the adoption of split conductor protection throughout the system, this practice being adopted on the overhead transmission lines as well as on the extensive cable network (see Fig. 2). All transmission circuits are so protected with the exception of two workshop feeders which are not split but are protected by pilot cables.

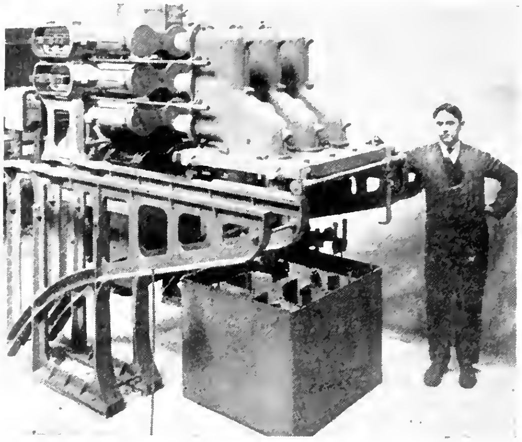


Fig. 3. Draw-out Type Switchgear with Buses Enclosed in Compound-filled Compartments. This type of switchgear is used in some of the Victorian Railway Substations

In lieu of lightning arresters, each overhead feeder is carried through two or three hundred feet of underground cable before entering the station. Feeder switches are of the split conductor type, the contacts being arranged so that the split conductors of each phase are connected together only when the switch is closed. By this means, faults at the distant end of a feeder will be cleared without the addition of end reactors. Other advantages such as convenience for testing are held to assist in justifying the extra expenditure involved in providing all single-pole circuit breaker units with three terminal bushings.

Of the substation equipment, the British Thomson-Houston Company supplied four 4500-kw. and eight 1000-kw. synchronous converters (the latter with automatic control) in which novel means have been adopted to prevent commutator flash-over due to d-c. short circuits.

The commutator is made the same diameter as the armature, and fan blades are fitted to the armature periphery, so that a strong air current flows outward axially across the face of the commutator in combination with a magnetic blow-out from the brush-holders. The hot gases from the brushes under short circuit conditions are thus prevented from reaching the adjacent brush-holder and establishing the highly destructive commutator flash-over. This type of construction is shown in Fig. 4.

The entire work of electrification was carried out to the plans and designs of Messrs. Merz and McLellan, consulting engineers of London, and under the direct supervision of their Melbourne office.

It is notable that the first car equipments exported by the General Electric Company, almost 30 years ago, were shipped to Melbourne.

The State Electricity Commission of Victoria

In 1919 the Victorian Government formed an Electricity Commission consisting of four members who are appointed by the Government. With the exception of the Chairman who devotes his entire time to his official duties, the appointments are honorary, the Commissioners receiving only a nominal fee for each meeting that they attend.

The powers of this commission are very wide. Not only does it act in the supervisory capacity of the Public Service Commissions of the United States, but at present it is engaged in the opening up of the Brown Coal Fields at Morwell, the construction of two 50,000-kw. power stations with 115-mile transmission line to Melbourne, terminal station, and substations. When power is available from this source, the Commission will sell power principally to municipalities and other retailers, but in some cases the Commission may sell direct to the consumers where expedient.

In 1921, after inviting and receiving tenders from the leading American and European manufacturers, the Commission entrusted the General Electric Company with contracts for all transformers, switchgear, etc., required in connection with the Morwell scheme, amounting in all to $1,500,000.

Fig. 4. Fan on Armature and Magnetic Blowout in Brush-holder for Prevention of Flash-over on 4500-kw., 1500-volt B.T-H. Synchronous Converter

In New South Wales, the State Government owns and operates all railways, steam and electric. The most important electric undertaking of the State is the power supply for the Sydney Tramways. The metropolitan population is 900,000. The famed beauty of Sydney and its harbor is a measure of the precipitous grades and tortuous curves over which the tramways must operate. Two steam stations, one at Ultimo and a more modern station at White Bay, have a combined installed capacity of 50,000 kilowatts (25 cycles), which will be increased shortly by the addition of (two) 20,000-kw. turbine-generators (50 cycles).

Figs. 5, 6, and 7 illustrate the White Bay station exterior, control room and switch gallery. This station, since its inception, has received much attention from Australian engineers and in many respects is regarded as a model.

The distribution system has recently been improved by the addition of several automatic substations.

A local pest that gave trouble in Sydney distribution systems in the past is the white ant. As is well known, this insect lives on wood and shuns the daylight, so that a wood pole may become a hollow shell and collapse without warning. White ants will also attack cables unless elaborate precautions are taken. Lead covering has no terrors for them, and the only effective protection appears to be that adopted in Sydney.

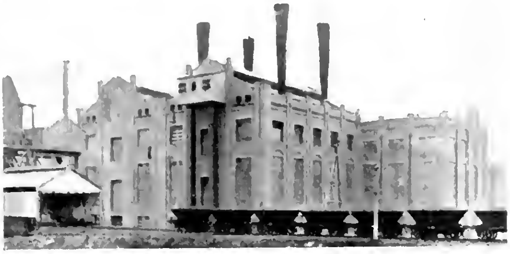


Fig. 5. White Bay Power House, New South Wales Government Tramways, with Venturi Type Smoke Stacks for Induced Draft

The lead covered cables are laid in troughing constructed of timber which has been vacuum dried and then impregnated under pressure with arsenic.

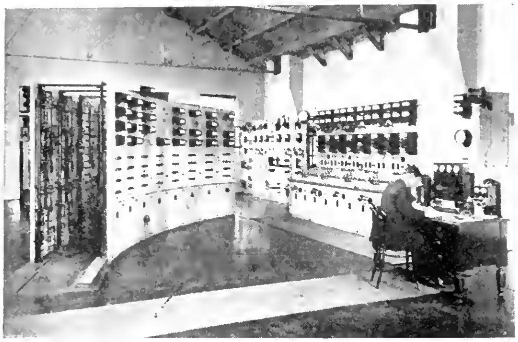


Fig. 6. Control Room of the White Bay Power House

After the cables are laid, the troughing is filled with bitumen to which arsenic has been added.

There is no recorded case of cable breakdown caused by white ants where these precautions were taken.

The Public Works Department of the Government is also interested in the generation and distribution of electric power. So far the larger power projects that have been planned by the department have not been carried out owing to consideration of finance.

There is every indication, however, that the Government of New South Wales intends to take a very active part in the electrical development of the state. The Government has recently contracted to supply the Municipal Council of Sydney with the future requirements beyond the capacity of its existing station.

Fig. 7. Switch Gallery of the White Bay Power House. Cell doors are of wood and glass

New Zealand Government, Public Works Department

This Government, like that of Tasmania, has shown great activity in developing the water-power with which Nature has lavishly endowed New Zealand. The first Government venture in this direction was commenced about ten years ago at Lake Coleridge in the South Island. This development of 12,000 kw. has been of great benefit to the territory served, which contains the rich pastoral lands known as the Canterbury Plains. The Government has made its electric service particularly attractive to the many dairy farms in the district, where agricultural labor is always scarce and expensive.

In consequence, the use of electric power is universal throughout these farms and hand milking is almost unknown. The ability to flood all the out-buildings with light has eliminated much of the early morning discomfort of dairy farming.

In the South Island the transmission network voltage will probably remain at 66,000. This has been adopted at Lake Coleridge and also at the 14,000-kw. plant now being built at Lake Monowai in the extreme south.

Between these two plants lies the City of Dunedin's development at Waipori Falls from which the city has enjoyed the benefits of hydro-electricity for many years.

It will probably be sometime in the future before the South Island systems are linked up into one system.

In the North Island (see Fig. 8) the most important development at present is that at Mangahao where a hydro-electric development of 24,000 h.p. is now in construction and will be in operation very soon. This will immediately supply Wellington, the capital city, and the surrounding country. The next development will be at Arapuni Rapids where 96,000 h.p. will be developed to supply Auckland in the north. The third is at Lake Waikaremoana which will add 40,000 h.p. to the system. These hydro-electric plants when completed and connected together will enable the North Island to be covered with a reticulation of 110,000-volt lines, 1100 miles in length.

Conclusion

The foregoing remarks on Australasia's electrical development will serve to indicate that the utilization of the available resources has been by no means neglected. In accordance with the settled policy of these countries on the question of public ownership, private enterprise is not encouraged. On the utilization of electricity for large public works such as railway electrification, the various political bodies responsible, their technical advisers, and the general public are all well-informed—the public more so than in other countries. This may be due to the press, which wields tremendous power in the Antipodes. At least one Australian daily newspaper reserves space regularly for the treatment of engineering questions in a manner that appeals to the majority of readers and the articles printed are nearly always illustrated.

For the same reason they are no more backward than the countries of the Northern Hemisphere in the domestic use of electric power.

The big field for development lies in manufacturing industry—the big power consumer in any country. The mainstay of these southern countries has been, and for some time to come will be, the products of farm and mine; but it did not require the lesson of the War and its aftermath to teach them that no nation can maintain a high standard of living and survive without the magic aid of power applied freely to manufacturing processes, thus maintaining a balanced economic structure.

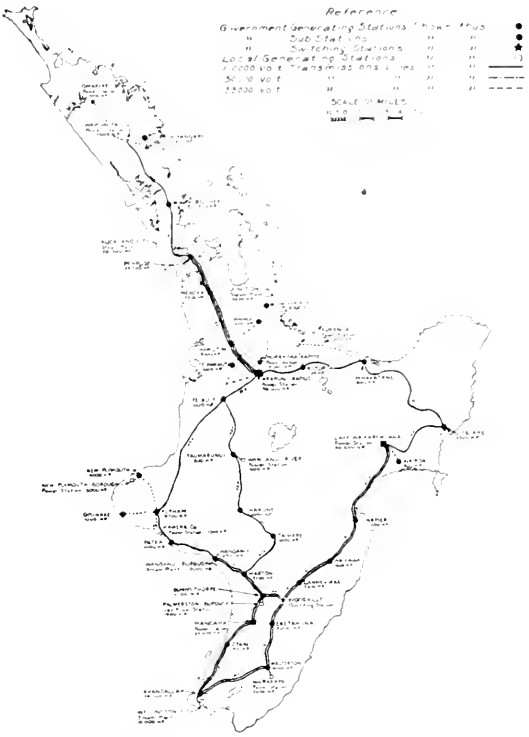


Fig. 8. Map of North Island, New Zealand, showing Transmission Network. Map prepared by Hydro-electric Branch of Public Works, New Zealand

While this review of electrical development deals with the subject mainly from the engineering standpoint, mention must be made of the pioneer work done in Australia by the various associations of contractors and dealers. Many of these are actively engaged in valuable educational work which must have a profound effect on the rate of electrical progress.

Some Fundamentals in Protecting Against Lightning

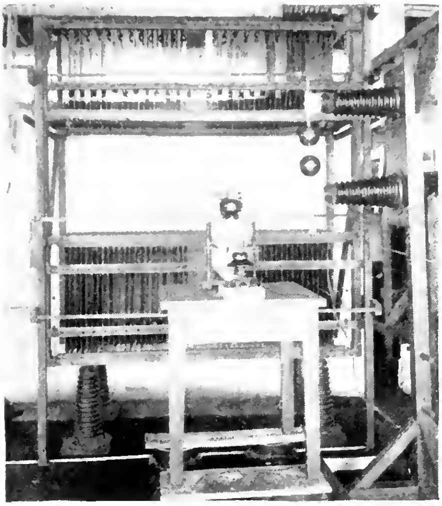
By E. E. Burger

General Engineering Laboratory, General Electric Company

To give adequate protection against lightning an arrester must have certain fundamental qualities. To design a set of tests which will determine in what degree a given type of arrester possesses these essential qualities has taken years of study. The author discusses the fundamentals which should be considered in the commercial testing of lightning arresters. These conclusions were based on experiments made in the General Engineering Laboratory in February, 1923.—Editor.

For some time past the American Institute of Electrical Engineers has felt the need of revising its standards in regard to lightning arrester tests, so that definite recommendations could be made as to the tests required and the manner of making them. It is also desirable that such tests represent service conditions as far as possible.

For many years Dr. C. P. Steinmetz has been making a study of lightning, and the transient phenomena which result from it on transmission and distribution circuits. Comparatively recently he has been able to design and build apparatus which is capable of reproducing the same effects as actual lightning. This apparatus was first described in the General Electric Review, November, 1921. With this apparatus our knowledge of lightning arrester performance has been increased, and it is hoped that in the near future a method of test will be devised whereby the true characteristics of lightning arresters can be determined before placing them in service. Many of the characteristics that a lightning arrester should have, and various descriptions of arresters and tests have been given in earlier issues of the General Electric Review.*



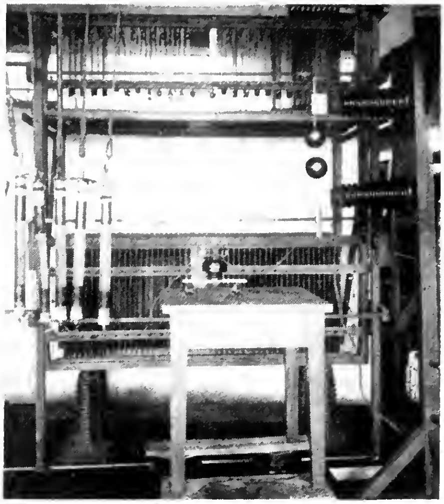


Fig. 1. (Left) 500-amp., 120,000-volt Discharge from Lightning Generator Between 6.25-cm. Spheres

Fig. 2. (Center) Aluminum-type Lightning Arrester and Insulator as Arranged for Test with Lightning Generator

Fig. 3. (Right) Resistance-type Lightning Arrester Composed of Five Water Tubes and a Series Gap as Arranged for Test with the Generator

During the present year the American Institute of Electrical Engineers' Protective Device Sub-Committee on Lightning Arresters held their meeting at Schenectady, and in the General Engineering Laboratory of the General Electric Company witnessed a series of tests which demonstrated a few of the fundamental characteristics which should be considered in lightning protection. The tests that were made before this committee will now be described.

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*See General Electric Review, November, 1920, "Performance and Life Tests on the Oxide Film Lightning Arrester," by N. A. Lougee. See also General Electric Review, December, 1921, "Types of Lightning Arresters," by J. L. R. Hayden and N. A. Lougee.

Tests

The tests are divided into a number of groups, with each group demonstrating some particular fundamental.

Preliminary tests were made to show the observers that the discharge from the lightning generator had all the external characteristics of real lightning. Several short lengths of tree branch were split into pieces by the discharge, the same effect having often been observed after an electric storm when trees have been found split down the center or the bark stripped off by a lightning bolt. Then the bright flash and sharp report simulated in miniature real lightning when it discharges from cloud to ground at close range.

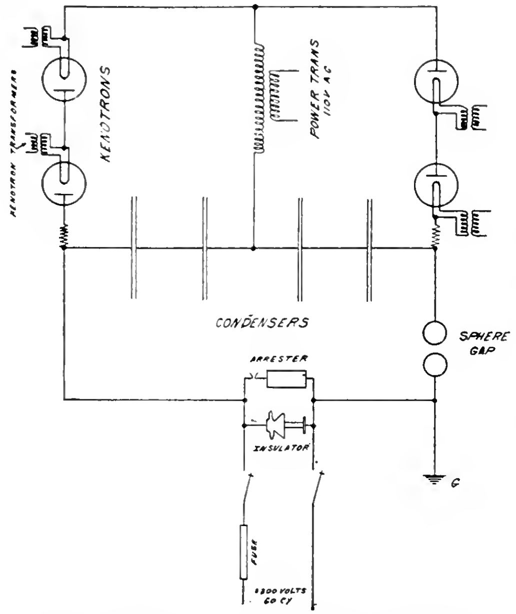

Fig. 4. Diagram of Connections, showing Lightning Arrester and Insulator Connected in Discharge Circuit of Lightning Generator

The first group of tests were made to show the power, energy and voltage of the testing circuit. A 15,000-volt standard pin-type insulator was connected in the path of the discharge and the ease with which it arced over the edges showed that the voltage was sufficient for test purposes on apparatus having insulation of equal strength. The energy of the impulse was demonstrated when a short length of 5-ampere fuse wire was placed in the discharge circuit and, after several discharges, was heated just enough to separate the wire in one or two places. The current that is discharged in the above test has been measured at approximately 5000 amperes. Thus the energy as measured by the heat produced must be very small. This test also shows that lightning arresters, which are protected in service against damage from low frequency discharges by series fuses, are capable of discharging a large amount of current for the duration of a lightning discharge without damaging or blowing the fuse.

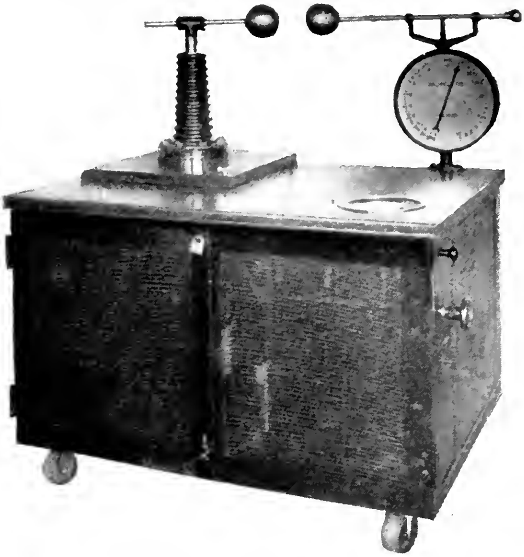

Fig. 5. 125-kv. High-frequency Oscillator with Sphere-gap Voltmeter

The second group of tests were made to demonstrate the importance of the discharge rate in lightning arrester design. The discharge rate of a lightning arrester is briefly defined as the rate at which the released charge on the line due to lightning is discharged to ground. This discharge rate is measured in amperes at some reference potential such as two times normal line potential. The tests were made to show that the higher the discharge rate of an arrester the better protection it gives, and also that this discharge rate is largely affected by the impedance of the discharge path. A 2300-volt aluminum cell arrester having a high discharge rate was shown protecting a 15,000-volt insulator which had been previously arced over. A power supply of 400 kv-a. at 2300 volts, 60 cycles, was connected to the arrester and the insulator while the impulses or discharges were passing through the circuit. The insulator was protected without any signs of distress or interruption of the power supply. Next, an arrester composed of a water tube resistance and a horn gap in series was used to replace the aluminum arrester. This arrester had a very low discharge rate and was capable of discharging approximately 17 amperes at the test voltage used. When impulses were passed through this circuit, the insulator arced over and short circuited the 2300-volt, 60-cycle power supply. The power supply was protected against damage by a fuse which quickly opened the circuit. The tests were then repeated using resistances which would give 2, 3 and 5 times the discharge rate or 34, 51 and 85 amperes respectively. In each of these tests the arrester failed to protect the insulator.

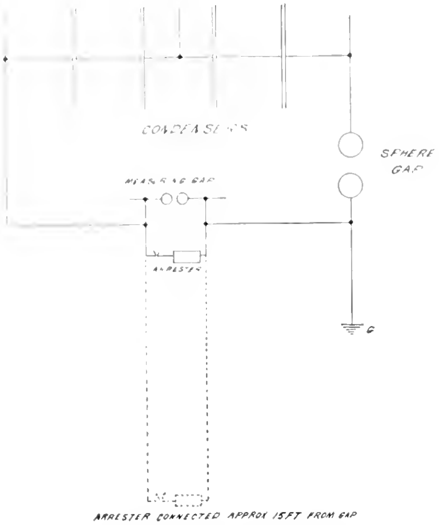

Fig. 6. Diagram of Connections, showing Lightning Arrester Arranged to Protect Gap with Long and Short Connections

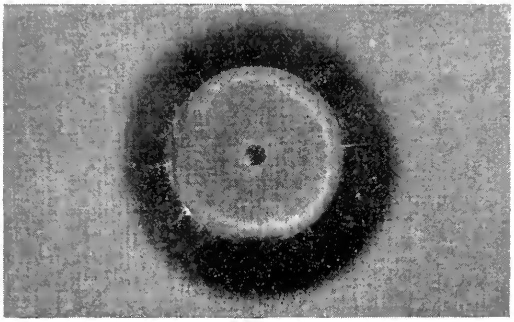

Fig. 7. Varnished Cambric Insulation Punctured by 0.75-amp. Current from 200,000-cycle Oscillator

To demonstrate further how resistance will affect the discharge rate of an arrester, tests were made to measure the voltage across the aluminum cell arrester, first alone, and then with 25, 50 and 100 ohms in series. The voltage of the arrester alone gave about 20.8 kv. and the arrester and resistance in series gave 50, 56 and 66 kv. respectively, showing that the discharge rate was decreased by the resistance and the additional voltage was due to the backing up of the discharge. From these tests it can be concluded that an arrester, which has high series internal resistance, must have a low discharge rate, or, in other words, have a low degree of protection.

The third group of tests were made to demonstrate how test results will differ with the method of test used. Voltage measurements were made on an aluminum arrester having a high discharge rate and the resistance arrester having a low discharge rate by two different methods of test. The first method, the same as used in some of the previous tests, was that of using a high voltage, steep wave front impulse of high current and high power for a short duration of time. The second method was to use a high voltage, high frequency oscillation of low current and low power for a comparatively long duration of time. The impulse generator and oscillator were set for the same test voltage, 85 kv. The impulse generator was capable of discharging 5000 amperes at this voltage and the 200,000-cycle oscillator about 0.75 amperes. The voltage values given below clearly show that in testing arresters care must be used in choosing a method of test so that true indications of protection will be given.

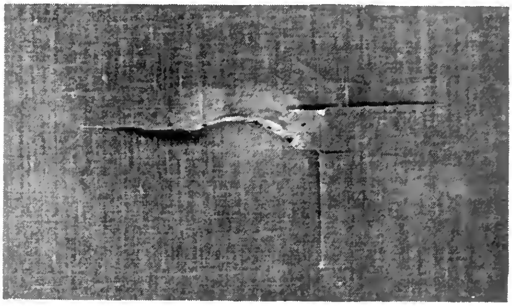

Fig. 8. Varnished Cambric Insulation Punctured by 5000-amp. Discharge from Lightning Generator

	Impulse Generator	Oscillator
Aluminum Arrester...........	20.8 kv.	10.4 kv.
Resistance Arrester, greater than	70.0 kv.	26.4 kv.

The fourth group of tests were made to demonstrate the importance of installing lightning arresters close to the apparatus to be protected. The aluminum arrester was shown protecting a small air gap between spheres with the connecting wires between gap and arrester about two feet long. The second test showed the same arrester failing to protect the same gap with fifteen or more feet of connecting wire between the arrester and the gap. When the gap was increased to five times its initial value, the arrester protected it.

The last group of tests were made to demonstrate what different results might be expected on the breakdown of insulation when taken with non-oscillatory transients of steep wave front and transients of undamped oscillations. Several thicknesses of mica and varnished cambric, 15 inches square, were punctured by the discharge from the impulse generator which tore the insulation as though some solid substance had been shot through it. There was no sign of burning due to the discharge and the breakdown was instantaneous. The same thicknesses of insulation were then punctured using the high frequency oscillator at the same test voltage. The voltage was applied for several minutes before breakdown occurred. Corona formed on the surface around the electrodes and the insulation became heated and carbonized before breakdown occurred. The breakdown formed a small carbonized hole in the insulation which later caught fire.

The Solution of Electric Power Transmission Problems in the Laboratory by Miniature Circuits

By O. R. Schurig
General Engineering Laboratory, General Electric Company

In our June, 1923, issue we published an article by F. W. Peek, Jr., on "Applying the Results of High-voltage Research to Practice." Our present contribution shows how miniature circuits are employed to solve transmission problems. Long lines present special problems and the author shows how these are handled. He deals with "smooth" and "lumpy" miniature lines and with complete transmission system networks. He gives the procedure of solving a typical network problem.—Editor.

Foreword

It is the object of this article to outline the established processes by which transmission circuits in operation, or to be constructed, may be reproduced on a small scale in the laboratory. Thus, theoretically calculated phenomena may be confirmed experimentally in a simple manner. Moreover, miniature systems afford a number of practical advantages in the experimental solution of specific circuit problems

PROBLEMS ON LONG LINES

The most elementary conception of an electric circuit involves the assumption that all parts of the same conductor carry one and the same current at any one time. If the current be alternating and of constant effective value, it varies uniformly between definite constant limits in a continuously recurring cycle. Its variation is then a function of *time*, but at any one instant the current is the same at all points of an insulated conductor. Should this conductor, however, be that of a long aerial high-voltage transmission line, several hundred miles long, the instantaneous currents measured at widely remote points of this line would no longer be the same, because of the capacity charging current required to charge the line; i.e., there is a continuous drain of current from the line, mile after mile. Furthermore, the time required for the current and potential to advance over a long line becomes an appreciable factor in the electrical behavior of the line. Consequently, on long lines, voltage and current vary not only with *time* but also with *distance along the line*. Both time and distance, then, determine the magnitudes and phases of current and voltage.

Ohm's law and Kirchhoff's law still hold, but must be applied to an infinitesimal length of line. This procedure results in differential equations—not of the simplest kind—for the solution of transmission-line behavior.* Thus, if it is desired to determine

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* See C. P. Steinmetz's "Transient Electric Phenomena," Section 4.

the voltage and current in the steady state at the generator end of a long line for given values of voltage, current and power-factor at the receiver end, the calculations may be made by the well-known hyperbolic formulas or by the exponential formulas.* The calculation of transient phenomena, such as those caused by switching operations, lightning, arcing grounds, etc., is more complicated than that of steady-state phenomena. Thus, a demand was created for the *experimental solution* of long-line problems—both of the transient and of the steady-state variety.

MINIATURE REPRESENTATION OF LONG LINES

Since experiments on active, real lines are not often practical, and since it is generally desirable to determine the electrical behavior of a line before it is built, miniature laboratory models of full-size lines have come into existence. Their use is not new. They have aided materially in the acceptance by engineers of the theory of transmission-line calculations.

"Smooth" Type of Miniature Line

Miniature laboratory transmission-line models—also called "artificial lines"—do not involve poles, towers, or cross-arms, but consist of units of resistance, inductance, capacity, and leakance, designed so as to represent, in true proportion, the constants of a full-size line. Let it be desired, for example, to reproduce in miniature a 60-cycle, 200,000-volt, 3-phase line, having copper cables of 350,000 cir. mils cross section, with 20 ft. spacing between conductors arranged equilaterally. The constants of this line are given in Table I, as determined by the well-known formulas for resistance, inductance and capacity of aerial conductors.

TABLE I

LINE CONSTANTS, FOR 60-CYCLE, 200-KV., 3-PHASE AERIAL LINE OF 350,000 CIR.-MIL COPPER CABLES, EQUILATERAL SPACING 20 FT.

Resistance	$r=0.163$ ohms per mile per conductor
Inductance	$L=0.002237$ henry per mile per conductor
Inductive reactance (at 60 cyc./sec.)	$2\pi fL=0.843$ ohm per mile per conductor
Capacity	$C=0.0136\times10^{-6}$ farad per mile per conductor to neutral
Capacity susceptance	$2\pi fC=5.13\times10^{-6}$ mhos per mile per conductor to neutral

The leakage conductance over insulators, etc., is negligible in comparison with the capacity susceptance and will therefore be considered equal to zero.

An electrically equivalent model of this line would therefore require for each hundred miles the following constants per conductor: resistance 16.3 ohms, inductive reactance (at 60 cycles) 84.3 ohms, capacity 1.36 microfarads. To be an exact replica of the 200-kv. line in question (to the extent of correctly representing the behavior of the full-size line at all frequencies for transient as well as sustained phenomena), the miniature line must be of the "smooth" type, i.e., one having uniformly distributed resistance, reactance, and capacity. Such models have been built. One† consists of turns of wire in a single layer wound over glass tubes having a lining of metal foil fitted against the inner wall of the glass. Another type of smooth artificial line‡ employs coils of several layers of uniformly wound wire; the uniformly distributed capacity is obtained by the use of metal foil wrapped over each layer of wire. A three-phase miniature circuit requires three similar elements, one for each phase, the metal foil terminals for the three elements being joined together to form the neutral of the three-phase system.

"Lumpy" Types of Miniature Line

While the smooth type of miniature line is particularly suited for the experimental study of transient phenomena involving high frequencies well above 60 cycles per second, the special construction for strictly uniform distribution of line constants is not necessary for low-frequency problems; in other words, a simpler construction of miniature circuit elements, in the form of separate units of resistance, of reactance and of capacity, is permissible. This type of miniature line, called "lumpy," is more common than the smooth type. Lumpy artificial lines

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* See A. E. Kennelly's "Hyperbolic Functions Applied to Electrical Engineering Problems," McGraw, 1916; Chap. 7, p. 86; and C. P. Steinmetz's "Transient Electric Phenomena."

† J. H. Cunningham, *A.I.E.E. Trans.*, 1911, Vol. 30, Part 1, p. 245.

‡ Designed by M. I. Pupin; *Trans. A.I.E.E.*, March, 1899; Vol. 16, p. 93.

may be made to represent one conductor to neutral, or all three phases, of a three-phase line.

In the use of a lumpy artificial line caution must be exercised on account of the fact that such a line of fixed constants does not represent, at all frequencies, the true equivalent of one and the same full-size line. Two questions, therefore, arise: (1) how is the correct magnitude of the lumps to be determined at any one frequency, and (2) what is the proper manner of connecting the resistance, inductance and capacity units of the miniature circuit?

The second question will be answered first: each phase, to neutral, may be represented either as in Fig. 1 (T-line)* or as in Fig. 2 (π-line).* For a uniform transmission line, the elements of either arrangement are symmetrical. A long line may be represented by a number of equal T or π sections with the resistance and inductance units connected in series with AB, and with the free terminal of each capacity unit connected to a common "neutral" point. The various sections so joined together represent, then, equally long sections of the transmission line, and *observations of voltage, current and power at the section junctions A and B of the miniature line indicate the correct behavior of the corresponding points of the full-size line.* Observations taken at points other than the section junctions or terminals of the miniature line are not representative of actual-line conditions. The advantage of employing *several* sections each equivalent to a *short* length of line are the following: (1) opportunity is offered for making observations at a number of equally spaced points throughout a long line; (2) practical equivalence of miniature and actual lines is obtained over a wider range of frequencies.

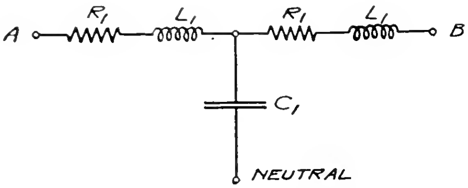
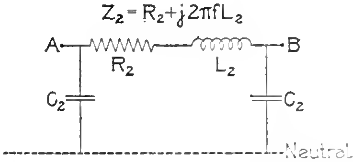


Fig. 1. Circuit Diagram of Miniature T-Line, representing One Phase (to Neutral) of a Three-phase Transmission Line

Lumpy Miniature Circuits at Different Frequencies

At low frequencies and for sections representing short lengths of line the magnitude of the lumps is obtained directly, without correction, from the constants of the full-size line. Thus, the 60-cycle, 200,000-volt line considered in Table I, may be reproduced in 10-mile π-sections derived as in Table II.

If, however, the equivalent length of a section is increased, or if the frequency is materially raised, the lumpy-line constants must no longer be made exactly proportional to the smooth-line constants, but must be obtained as follows, in the case of a π-line, (see Fig. 2):



For each condenser element to neutral, the admittance is

$$Y_2 = j2\pi fC_2$$

when leakage resistance is present, represented as a resistance r_2 in parallel with C_2, the admittance Y_2 becomes

$$Y_2 = G_2 + j2\pi fC_2$$

where $G_2 = \frac{1}{r_2}$

Fig. 2. Circuit Diagram of Miniature π-line, representing One Phase (to Neutral) of a Three-phase Transmission Line

$$Z_2 = lz\left[\frac{\sinh\theta}{\theta}\right] = lzk_l \qquad (1)$$

$$Y_2 = \frac{ly}{2}\left[\frac{\tanh\left(\frac{\theta}{2}\right)}{\left(\frac{\theta}{2}\right)}\right] = \frac{ly}{2}k_c \qquad (2)$$

The symbols are defined as follows:

(1) actual-line data:

l = length of section in miles.

$z = r + j\omega L$ = line impedance, ohms per mile per conductor.

$y = g + j\omega C$ = admittance, mhos per mile per conductor to neutral.

$\theta = l\sqrt{zy}$ = total hyperbolic line angle per conductor, for section l miles long.

$\omega = 2\ \pi f$.

f = frequency, cycles per second.

$j = \sqrt{-1}$.

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* This nomenclature and the diagrammatic representation shown in Figs. 1 and 2 are those employed on p. 88, Figs. 47 and 48 of A. E. Kennelly's "Hyperbolic Functions Applied to Electrical Engineering Problems," McGraw, 1916.

(2) equivalent π-line data, representing a section l miles long:

$Z_2 = R_2 + j\omega L_2$ ohms impedance of line element (see Fig. 2).

$Y_2 = G_2 + j\omega C_2$ mhos admittance of each capacity element of π line.

G_2 = mhos leakage conductance associated with each capacity element; when g, the leakage conductance per conductor to neutral for the actual line, is of negligibly small magnitude (as in the case of well insulated lines in dry weather), G_2 also is small in comparison with the capacity susceptance $j\omega C_2$.

k_l and k_c are the equivalent π-line correction factors,* shown by the square brackets of equations (1) and (2), respectively; k_l may be called the line-element correction factor and k_c the condenser-element correction factor, for an equivalent π circuit.

$$\theta = l\sqrt{zy} =$$
$$200\sqrt{0.859\,\underline{/79.^\circ1} \times 5.13 \times 10^{-6}\,\underline{/90^\circ}}$$
$$= 0.420\,\underline{/84.^\circ6}$$

$$Z_2 = lz\,\frac{\sinh\theta}{\theta} =$$
$$200 \times 0.859\,\underline{/79.^\circ1} \times \frac{\sinh 0.420\,\underline{/84.^\circ6}}{0.420\,\underline{/84.^\circ6}}$$
$$= 167.0\,\underline{/79.^\circ5} \text{ ohms}$$

or

$$Z_2 = 30.45 + j\,164.1 \text{ ohms.}$$

Similarly, from equation (2)

$$Y_2 = \frac{ly}{2} \cdot \frac{\tanh\left(\frac{\theta}{2}\right)}{\left(\frac{\theta}{2}\right)}$$
$$= \frac{200 \times 5.13 \times 10^{-6}\,\underline{/90^\circ}}{2}\,\frac{\tanh 0.210\,\underline{/84.6^\circ}}{0.210\,\underline{/84.6^\circ}}$$
$$= 521 \times 10^{-6}\,\underline{/89.^\circ8} \text{ mhos.}$$

TABLE II

	Uniformly Distributed Constants of Actual Line; Total Values per Conductor for a Ten-mile Length	Equivalent "Lumped" Constants of Miniature π-line, 10-mile Section, for 60 Cycles. The Symbols Refer to Fig. 2
Resistance	1.63 ohms	$R_2 = 1.63$ ohms
Inductance	0.0224 henry	$L_2 = 0.0224$ henry
Capacity to neutral	0.136×10^{-6} farad	$C_2 = 0.068 \times 10^{-6}$ farad for each capacity element

Example of Miniature Line Equivalent to a Power Line

For the 200-kv. line considered in Tables I and II, a strictly equivalent miniature π-section representing 200 miles of line, for steady-state conditions, is determined as follows from the line data of Table I (leakage conductance is neglected):

Two cases are considered: (1) for the fundamental frequency (60 cycles per second) and (2) for the third-harmonic frequency (180 cycles per second).

Case 1. f = 60 cycles per second

$l = 200$ miles.

$z = r + j\omega L = 0.163 + j\,0.843 = 0.859\,\underline{/79.^\circ1}$ ohms per mile.

$y = g + j\omega C = o + j\,5.13 \times 10^{-6} = 5.13 \times 10^{-6}\,\underline{/90^\circ}$ mhos per mile.

or

$$Y_2 = (1.8 + j\,521) \times 10^{-6} \text{ mhos}$$

Case 2. f = 180 cycles per second.

$l = 200$ miles.

$z = 0.163 + j\,2.529 = 2.533\,\underline{/86^\circ}$ ohms per mile.

$y = o + j\,15.39 \times 10^{-6} = 15.39 \times 10^{-6}\,\underline{/90^\circ}$ mhos per mile.

$$\theta = 200\sqrt{2.533\,\underline{/86^\circ} \times 15.39 \times 10^{-6}\,\underline{/90^\circ}}$$
$$= 1.25\,\underline{/88^\circ}.$$

$$Z_2 = 200 \times 2.533\,\underline{/86^\circ}\,\frac{\sinh 1.25\,\underline{/88^\circ}}{1.25\,\underline{/88^\circ}}$$
$$= 506.6\,\underline{/86^\circ} \times 0.760\,\underline{/1.^\circ2} = 385.\,\underline{/87.^\circ2} \text{ ohms}$$

or

$$Z_2 = 18.9 + j\,384. \text{ ohms}$$

and

$$Y_2 = \frac{200 \times 15.39 \times 10^{-6}\,\underline{/90^\circ}}{2}\,\frac{\tanh 0.625\,\underline{/88^\circ}}{0.625\,\underline{/88^\circ}}$$
$$= 1539 \times 10^{-6}\,\underline{/90} \times 1.155\,\overline{0.^\circ6}$$
$$= 1778 \times 10^{-6}\,\underline{/89.^\circ4}$$
$$= (19 + j\,1778) \times 10^{-6} \text{ mhos.}$$

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* For the equivalent T-line, the same correction factors apply, but change places with each other; i.e., for the T-line, the factor involving the hyperbolic tangent of half the line angle is used for each of the series line elements, while the factor involving the hyperbolic sine of the line angle is used for the capacity element of the T-line (see A. E. Kennelly's "Hyperbolic Functions Applied to Electrical Engineering Problems," McGraw, 1916, pp. 31–33).

The results of the two cases may be summarized as follows in Table III:

In order, then, to represent correctly (as to terminal conditions) the given 200-kv. actual line of 200 miles, for its *60-cycle* steady-state behavior, the equivalent one-section π-line must have the constants indicated in the 60-cycle column of Table III. In order, however, to represent the identical full-size line, for its *180-cycle* steady-state behavior, the π-line constants in the last column of Table III must be employed. It is seen that the values of resistance, reactance, and capacity for an equivalent lumpy line differ appreciably from the nominal values for the uniformly distributed (or "smooth") type of line, under the conditions chosen in the above example. The difference between nominal and equivalent values is seen to be small at 60 cycles, but is considerable at 180 cycles.

TABLE III

COMPARISON OF SMOOTH-LINE AND EQUIVALENT π-LINE CONSTANTS FOR 60-CYCLE AND FOR 180-CYCLE FREQUENCIES

Nominal Values* for 200 Miles of "Smooth" Line	VALUES* FOR π-SECTION EQUIVALENT TO 200 MILES OF ACTUAL LINE; FOR SYMBOLS SEE FIG. 2	
	At 60 Cyc. per Sec.	At 180 Cyc. per Sec.
$200\ r = 32.6$ ohms	$R_2 = 30.5$ ohms	$R_2 = 18.9$ ohms
$200\ L = 0.447$ henry	$L_2 = 0.436$ henry	$L_2 = 0.340$ henry
† $\frac{200\ C}{2} = 1.36 \times 10^{-6}$ farad	$C_2 = 1.38 \times 10^{-6}$ farad	$C_2 = 1.57 \times 10^{-6}$ farad
‡ $\frac{200\ g}{2} = 0$	$G_2 = 1.8 \times 10^{-6}$ mho	$G_2 = 19 \times 10^{-6}$ mho
	60-cycle Correction Factors	180-cycle Correction Factors
Correction factor k_l for line element of π-line..........................	$0.971\ \underline{/0.^\circ 4}$	$0.760\ \underline{/1.^\circ 2}$
Correction factor k_c for each capacity element of π-line..................	$1.015\ \overline{\backslash 0.^\circ 2}$	$1.155\ \overline{\backslash 0.^\circ 6}$

* Values per conductor to neutral.

† Half the total capacity is used here because the value of $Y_2 = \frac{ly}{2} k_c$ from equation (2) reduces to $\frac{ly}{2}$ when $k_c = 1$.

‡ Leakage conductance associated with capacity.

MINIATURE REPRESENTATION OF COMPLETE TRANSMISSION SYSTEM NETWORKS

The type of miniature circuit discussed in the foregoing is used primarily for the solution of *long-line problems* and for confirming the theory of such lines. Large modern electric power systems, however, generally have a network of lines. Thus, a great many of their problems involve simultaneous consideration of the transmission network together with the station apparatus, and require for experimental solution in the laboratory a *miniature transmission network with miniature station apparatus.* This kind of miniature system may have either *fixed* circuit constants and *fixed* system connections—for representation of one system only*—or it may have *adjustable* circuit constants and *variable* system connections. The "Short-circuit Calculating Table"† is of the latter type. Though based on an approximation, it serves for the quick experimental solution of a wide variety of short-circuit problems, but is limited to the determination of three-phase short-circuit currents.

The experimental solution of numerous problems pertaining to single-phase short circuits and to normal current flow (due to loads) in complex networks calls for a polyphase miniature system. A system of this kind is available in the General Engineering Laboratory at Schenectady. It includes synchronous machines and transformers for two generating stations (or substations), adjustable line units of resistance, inductance and capacity for eight three-phase lines (with loads), and switching arrangements for making any desired circuit connections. The switchboard for the entire miniature system and the table for measuring

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* A complete miniature system with substantially fixed circuit constants is described by G. H. Gray. *Trans. A.I.E.E.*, 1917, p. 789, Vol. 36.

† The original short circuit calculating table, due to Messrs. H. H. Dewey and W. W. Lewis, is described in the GENERAL ELECTRIC REVIEW, Oct. 1916, p. 901.

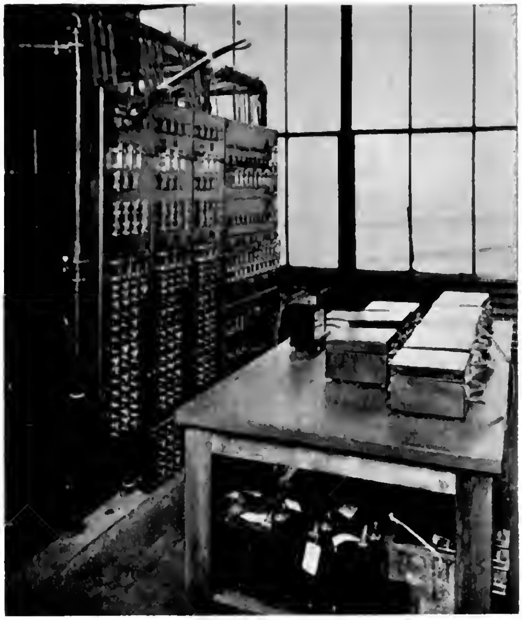

Fig. 3. Miniature Electric Power Transmission System. View of Switchboard and Instrument Table

instruments are pictured in Fig. 3. The current rating of the equipment is from 5 to 20 amperes, thus permitting the use of standard portable meters. A full description of this miniature system, together with a discussion of some of the problems for which it is suited, is given in a paper prepared for the June, 1923, Convention of the A.I.E.E.

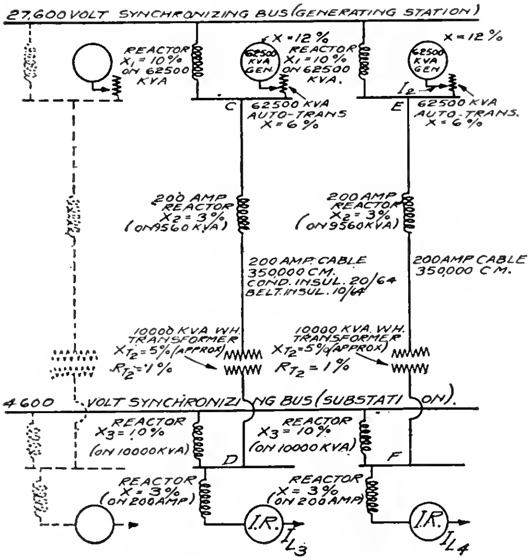

Fig. 4. One-line Diagram of Three-phase System with Full-size Circuit Data

PROCEDURE IN SOLVING A TYPICAL NETWORK PROBLEM

In the following example the problem of determination of normal current flow (due to loads) in a network will be considered. The object of this example is to show how the full-size circuit is converted into its equivalent miniature circuit for experimental solution.

A one-line diagram of the three-phase circuit to be represented in miniature is that of Fig. 4. Since the circuit constants and the loads in this 3-phase, 60-cycle system are balanced, it may be reproduced in miniature as a one-conductor circuit to neutral. Moreover, the series-connected circuit elements may be joined together into a single-circuit element, by the addition of impedances; and finally, all of the circuit constants are expressed in terms of one common reference kv-a. and voltage. After these transformations have been made, the circuit of Fig. 5 is obtained. The corresponding full-size circuit data are those of Table IV, column 2. The value of z_0, for example, is obtained as follows: From Fig. 4, z_0 represents the sum of two 10 per cent reactances (at 62,500 kv-a. base). From the formula

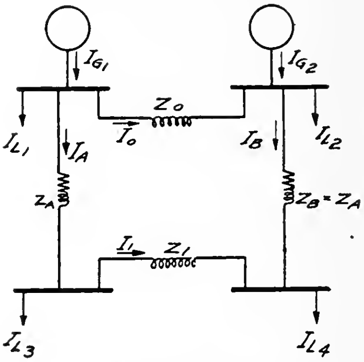

Fig. 5. One-line Diagrammatic Representation of Circuit of Fig. 4 for Calculation of Current Division

$$\text{Per cent reactance} = \frac{(\text{ohms reactance}) \times (3\phi\ \text{kv-a. basis})}{10\ (\text{kv. reference line voltage})^2}$$

the value of z_0 in ohms then is

$$z_0 = \frac{10 \times 20 \times 27.6^2}{62,500} = 2.44 \text{ ohms}$$

Since the cable lengths are not over 5 miles, capacity charging currents may be neglected. The full-size circuit load data appear in the lower part of column 2 in Table IV. For the single-conductor-to-neutral miniature representation of this system, convenient miniature values are:

200 volts line-to-neutral voltage.

7.0 amperes line current corresponding to 1305 full-size line current.

4.2 kv-a. equivalent 3-phase miniature kv-a. corresponding to 62,500 full-size system kv-a.

The determination of the miniature system impedance values will be illustrated in the case of z_0. Since the per cent drop through z_0 must be 20 per cent for both miniature and actual systems, the equivalent miniature value of z_0 is found as follows:

$$\text{Miniature } z_0 = \frac{10 \times 20 \times (0.2\sqrt{3})^2}{4.2} = 5.72 \text{ ohms.}$$

Thus the reduction factors from actual circuit to equivalent miniature circuit data are:

Factors based on 27,600 volts reference line voltage. Multiply full-size system values by these factors to get miniature-system values.

Volts	$\frac{1}{79.7}$
Amperes	$\frac{1}{186.5}$
Ohms	2.34

TABLE IV

FULL-SIZE AND MINIATURE LINE DATA FOR CIRCUIT OF FIG. 4, REPRESENTED DIAGRAMMATICALLY IN FIG. 5

1	2 Full-size Circuit Data at 27,600 Volts Reference Line Voltage	3 Equivalent Miniature Circuit Data at 346.4 Volts Reference Line Voltage
z_0 (reactance only)	2.44 ohms	5.72 ohms
R_A*	1.66 ohms	3.87 ohms
X_A*	7.20 ohms	16.8 ohms
z_1 (reactance only)	15.28 ohms	35.6 ohms
Line Current for 62,500 Kv-a.	1305 Amp.	7.0 Amp.
Load at I_{L1}	32,100 kv-a., 0.77 p-f.†	
Current I_{L1}‡	670 amp.	3.6 amp
Load at I_{L2}	50,000 kv-a., 0.90 p-f.†	
Current I_{L2}‡	1045 amp.	5.6 amp.
Load at I_{L3}	8,050 kv-a., 0.76 p-f.†	
Current I_{L3}‡	168 amp.	0.90 amp.
Load at I_{L4}	10,000 kv-a., 0.95 p-f.†	
Current I_{L4}‡	209 amp.	1.12 amp.
Current at I_{G2}‡	840 amp. 0.80 p-f.†	4.50 amp.

* R_A and X_A comprise reactor, transformer and cable; each cable is 5 miles long. The total per cent values referred to 10,000 kv-a. base are: Per cent $R_A = 2.18$ per cent; Per cent $X_A = 9.42$ per cent.

† Lagging.

‡ At normal reference line voltage, for balanced loads.

Obviously, the reciprocal values of the above factors serve for the conversion of the miniature test data to the corresponding actual system data. With the miniature circuit connected as in Fig. 5 and adjusted for the circuit constants of Table IV, column 3, the preparations are complete for test readings of any desired unknown currents, such as I_{G1}, I_A, I_B, I_0 and I_1. With the aid of voltage and watt readings the relative current phases are easily determined.

Solution by Calculation

The equations for the mathematical calculation of load-current flow in the network of Fig. 5 will be presented in the following to show the procedure in this (relatively simple) case. From this figure, the equations of the circuit are:

$$I_A + I_0 + I_{L1} = I_{L1} + I_{L2} + I_{L3} + I_{L4} - I_{G2} \qquad (3)$$

$$I_A z_A + I_1 z_1 = I_0 z_0 + I_B z_B \qquad (4)$$

$$I_A + I_B = I_{L3} + I_{L4} \qquad (5)$$

$$I_B + I_1 = I_{L4} \qquad (6)$$

From these equations the currents I_A, I_B, I_0, I_1 may be solved if the impedances z_A, z_B, z_0, z_1, the load currents I_{L1}, I_{L2}, I_{L3}, I_{L4}, and generator current I_{G2} are given.

From (6)

$$I_B = I_{L4} - I_1 \qquad (7)$$

From (7) and (5)

$$I_A = I_{L3} + I_1 \qquad (8)$$

From (3) and (8)

$$I_0 = I_{L2} + I_{L1} - I_{G2} - I_1 \qquad (9)$$

Substituting the expressions (7), (8), and (9) in equation (4) the solution for I_1 is:

$$I_1 = \frac{1}{z_A + z_B + z_0 + z_1} \times$$
$$[z_0(I_{L2} + I_{L1} - I_{G2}) + z_B\, I_{L4} - z_A\, I_{L3}] \qquad (10)$$

Finally, the expression for I_{G1} is

$$I_{G1} = I_{L1} + I_{L2} + I_{L3} + I_{L4} - I_{G2} \qquad (11)$$

With the value of I_1 from (10) the values of I_A, I_B and I_0 from (8), (7) and (9) may be expressed in terms of the known quantities.

All of the above equations are vector equations and may be solved either by complex algebra or graphically. The graphical solution is probably the simpler, because the solution by complex algebra involves the evaluation of eight equations, two for each of equations (10), (8), (7), and (9). Either of these solutions is lengthy in comparison with the test procedure.

Advantages of Experimental Solution

The advantages of the experimental solution are the following:

(1) Less time is consumed in obtaining answers.

(2) The results are easily checked by readings of instruments.

(3) Problems may be solved for which calculations are not practical.

(4) A variety of circuit conditions may be solved with *one* experimental set-up.

The last-mentioned factor is of great importance for a miniature system with *adjustable* circuit constants. In dealing, for instance, with a problem of normal-current division in a system, successive solutions for a variety of load conditions may quickly be obtained experimentally by adjustments of a rheostat or of a reactor, while solution by calculation requires computing, with new values for each load condition, the entire set of vector equations, or practically repeating the complete graphical solution.

In the solution of short-circuit-current problems, the advantages of the experimental procedure are even more pronounced, when the current flow for a variety of short-circuit locations in a network is to be determined. The reason will be seen when it is considered that each location of short circuit requires a new set of simultaneous equations for the mathematical solution.

Record Breaking Current Collection Tests at Erie

By W. D. Bearce

Railway Engineering Department, General Electric Company

The casual observer of our ordinary street trolley car seldom stops to think it is truly wonderful that sufficient current can be collected by a wheel rolling on a wire. How much contact surface is there? Who would design a switch with the same limited surface contact? To collect current for such service as the locomotives on the C., M. & St. P. Railway presents a real problem; but it was solved. The collection of currents as high as from 5000 to 6000 amperes has recently been demonstrated in a series of remarkable tests carried out at the Erie Works of the General Electric Company. The author describes these tests and the overhead construction and equipment used.—Editor.

A series of current collection tests was made before a group of prominent railroad men and engineers at Erie during the week of July 16. These tests were particularly important because of the remarkable ease with which currents of from 5000 to 6000 amperes were collected at speeds approximating 60 miles per hour with a complete absence of sparking. The occasion of this public exhibition was the demonstration, under actual operating conditions, of the collection of heavy currents from a single pantograph, if desired, at practically any operating speed. It was remarked during this demonstration that the amount of current collected from a single pantograph is far beyond the requirements of any single-unit electric locomotive for many years to come.

It is interesting to note that 5000 amperes represents 7500 kw. at 1500 volts or 15,000 kw. at 3000 volts. Heavy freight locomotive service, such as is handled by the C., M. & St. P. Railway requires a maximum of between 4000 and 5000 kw. for a 3000-ton train hauled by two units up a 2 per cent grade. The current for these locomotives is obtained at different points through a collector on each engine, and is in any case less than one-third the amount collected during the Erie tests. Heavy freight service at low speeds is being planned on the Virginian Railway, consisting of 6000-ton trains up a 2.2 per cent grade. This service would require approximately 10,000 kw. and would employ two or probably four collectors.

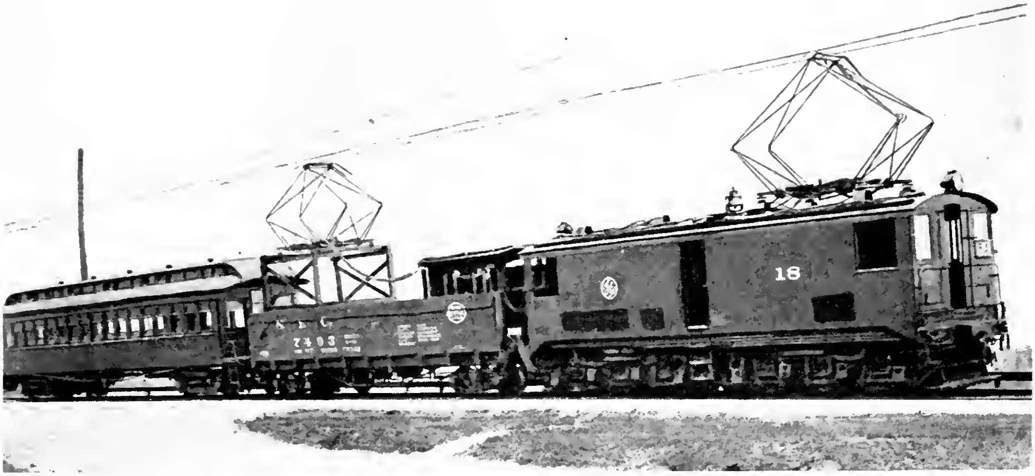

Fig. 1. The Test Train Consisting of a Locomotive, a Gondola Carrying a Second Pantograph and Loading Rheostats, and an Observation Coach

It is further of interest to make a comparison between the amount of energy collected from this type of overhead line construction with the well known trolley wheel collector as used in the heavier interurban service. With this latter equipment, the current ranges from about 800 amperes during acceleration down to 300 to 500 amperes at running speeds.

For successful current collection it is essential that the contacts between the working conductor and the collector be maintained. Any irregularity in the contact that may cause visible arcing must be avoided. Arcing at the contact is a much greater factor in the deterioration of the contact wire and collector than the mechanical wear due to the sliding friction. The type of overhead construction developed at Erie is designed to comply with these essential characteristics and has demonstrated the possibility of collecting an amount of current far in excess of that necessary to handle the heaviest trains.

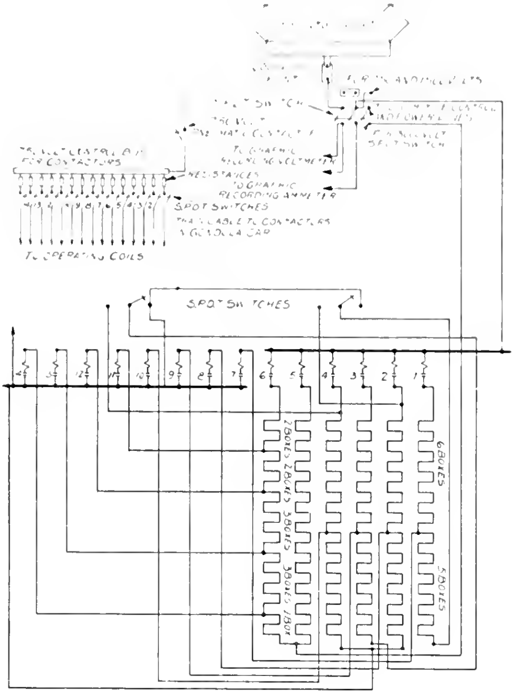

Fig. 2. Connection Diagram showing the Wiring of the Locomotive and Gondola

It should be noted that in all of these tests, the type of pantograph used is a duplicate of that now in operation on the C., M. & St. P. locomotives. The improvement in the capacity of the collecting equipment is due to the flexible type of overhead construction developed by General Electric engineers at the time the initial 3000-volt equipment was installed on the C., M. & St. P. Railway and consisting of loop hangers with a twin trolley supported from alternate points. This design is unusually flexible and represents a vast improvement over anything previously used.

In order to demonstrate to interested visitors the remarkable qualities of this type of construction, a series of tests was made using a special train, which is described hereafter, by means of which the amount of current flowing from the trolley wire to the locomotive could be regulated from the engine cab. The tests were run on three consecutive days, and the program was practically identical during each of these exhibitions. After preliminary inspection during the afternoon, the heavy current collection tests were started each day at about 5:00 p.m. The first test consisted of a run made at 4000 amperes and 1500 volts, reaching speeds of from 50 to 60 miles per hour with one pantograph. A second run was made under the same conditions after the visitors had been distributed to the several observation towers along the track. The second test was made at the same current but at reduced voltage to afford a comparison between operation at 1500 and 850 volts. This test was also repeated for the benefit of observers located along the track. On account of the limited capacity of the power station, the higher current tests were all made at 850 volts.

The third test was made at 5000 amperes 850 volts running at about 30 miles per hour with two pantographs. The object of this test was to show successful operation at moderate speeds. The final test on the regular program was made at 5000 amperes 850 volts at speeds between 50 and 60 miles per hour using two pantographs. This was repeated a sufficient number of times to allow observers located on the several towers to witness operation both from the train and from any one of the towers. At the request of some of the visiting engineers an extra run was made at 5000 amperes 850 volts high speed using only one pantograph. The actual speed obtained during this run was 58 miles per hour while drawing a current of 5400 amperes.

In all of these tests visitors noted a complete absence of sparking at the pantograph and no difference whatever could be observed between operation at 1500 and 850 volts. The tests indicate that the amount of current which can be collected is practically independent of the trolley voltage when contact is maintained between the collector and the working conductor. A further special test was made at the request of some of the visiting railroad men to show the effect of lowering the pantograph under load with the train at standstill. This test was performed directly in front of the substation and the standard relay protection interrupted the 5000-amp. 850-volt load before the pantograph could leave the wire. A second test was made with the relay disconnected and the arc formed was quickly extinguished as the collector dropped from the wire. At this time it was explained that in case of a reduction in the air pressure, which holds the pantograph against the wire, protection to the locomotive is afforded by a relay which opens the line switches thus eliminating the possibility of arcing from this cause.

Steel Structures

The steel supporting structures begin about 600 ft. west of the substation with latticed column bridges extending up to bridge No. 13. Bridges No. 14 to 18 inclusive are Bethlehem column bridges. The structures from No. 19 to 23 are latticed channel bracket poles; from No. 24 to 28 inclusive, 10-in. Bethlehem bracket poles; from No. 29 to 33 inclusive, 9-in. Bethlehem bracket poles. Bridge No. 34 is of the latticed column type used for an anchor. The steel structures are spaced 300 ft. throughout. All of the steel structural work was supplied by the Archbold Brady Co., Syracuse, N. Y.

Primary Messenger

The primary messenger consists of a $\frac{5}{8}$ in. 7-strand high-strength steel cable, from structure No. 1 to 34.

Secondary Messenger

The secondary messenger is a 1,000,000 circular mil stranded copper cable between bridges No. 1 and 15, and a 750,000 circular mil stranded copper cable from bridges No. 15 to 34.

Working Conductor

From bridges No. 1 to 16 and from No. 20 to 34, the working conductor consists of two No. 0000 grooved hard-drawn copper wires hanging side by side. From bridges No. 16 to 21 two No. 000000 copper wires are used.

Type of Suspension

Droppers from the primary messenger support the secondary messenger at points 15 ft. apart. The working conductors are supported from the secondary messenger by clips spaced 15 ft. apart on each wire.

Observation Towers

To witness current collection tests conveniently, observation towers had been erected to a height of approximately the top of the pantograph. Tower No. 1 is located between bridges No. 9 and 10 on the center of a reverse curve so that current collection can be observed on the curves approaching and leaving as well as on the connecting tangent. Tower No. 2 is located between bridges No. 14 and 15 on tangent level track. Towers No. 3, 4, and 5 are located farther east at intervals of about 1200 ft.

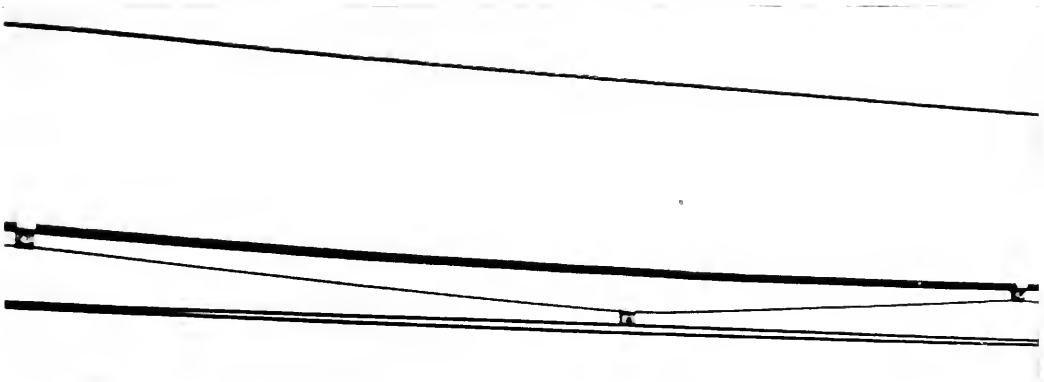

Fig. 3. A Close-up View of the Trolley Wire Suspension Used in the Tests

Substation

The substation in building No. 60 contains two synchronous motor-generator sets with switching equipment suitable for connecting these units to supply any trolley potential from 600 to 3000 volts. One of these sets has a rated capacity of 1000 kw. and consists of two 500-kw. 1500 3000-volt generators direct connected to a synchronous motor. The second unit is of similar construction but with

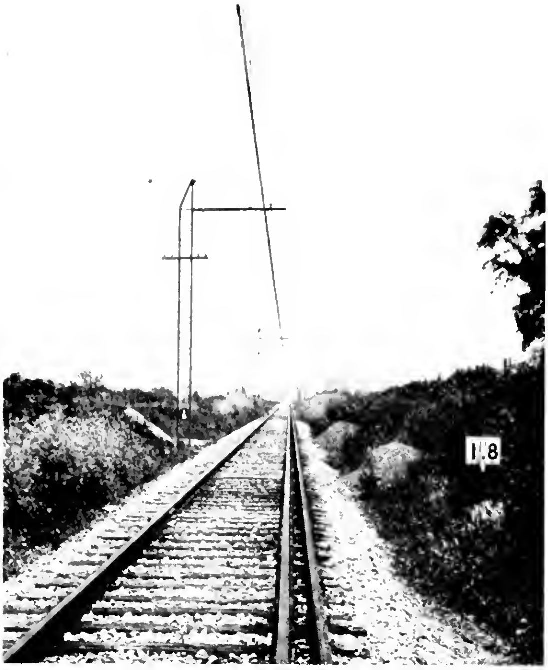

Fig. 4. The Overhead Trolley Suspended from Latticed Side Bracket Poles

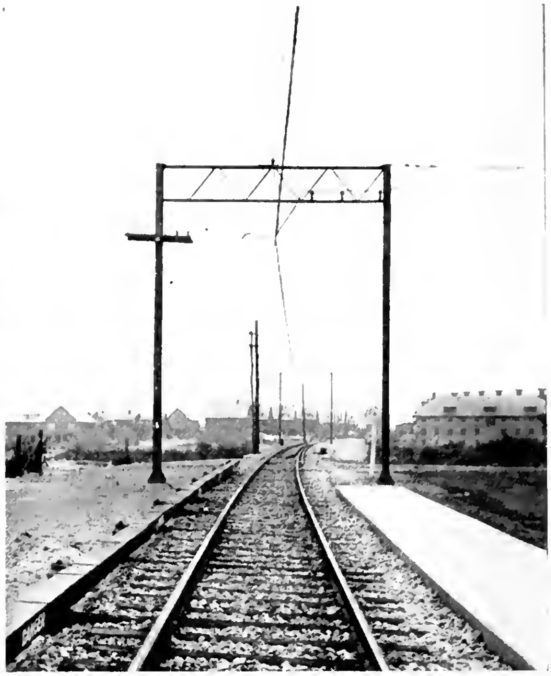

Fig. 5. The Overhead Suspension on a Curve in Front of the Substation

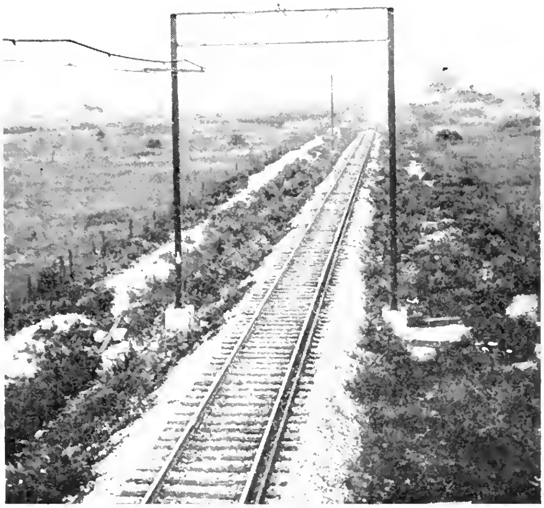

Fig. 6. A Tangent Section of the Tracks on which the Tests were Run

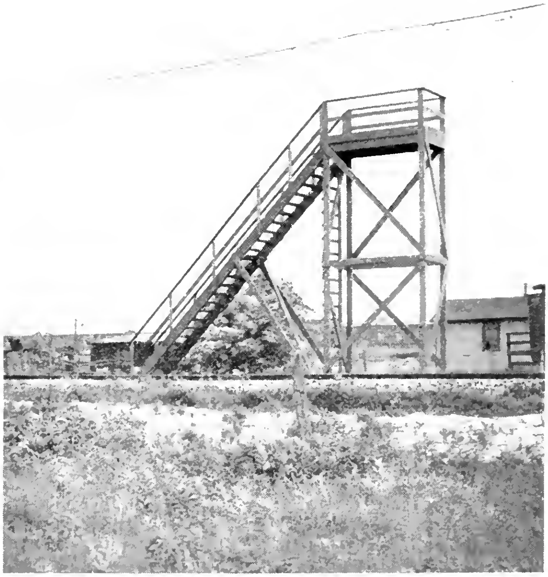

Fig. 7. One of the Several Observation Towers from which the Action of the Suspension was Conveniently Viewed

two 750-kw. generators. Full capacity can be obtained with both series and parallel connections, and lower voltages can be obtained by adjusting the rheostats in the generator fields. Both of these sets are designed to operate at three times normal load for short periods, and a total of 6000 kw. can be obtained, the limit of the power supply. All generators are protected by high-speed circuit breakers and the switching equipment and the meters and voltage control are especially arranged to facilitate testing.

The substation is located approximately nine-tenths of a mile from the west end of the track. Building No. 60 also serves the purpose of a shop and contains four tracks for the entire length. Pits underneath these tracks facilitate inspection and repairs to equipment.

Locomotive Scales

On one of these tracks there is also an elaborate weighing equipment* for determining the weight per axle of locomotives under test. There are a total of eight scales which can be moved to accommodate different wheel spacing so that simultaneous weights can be taken on all of the axles of a locomotive. Each scale has a capacity of 80,000 lb. and the entire set occupies a pit 78 ft. long. By means of air pressure the entire locomotive can be lifted at once or any axle separately. The distance which the wheels are lifted to bring the weight onto the scale is about ¾ in.

Test Train

For the current collection tests, a special train had been prepared consisting of a 110-ton gearless locomotive arranged for operation on 750/1500 volts followed by a gondola furnished by the New York Central R. R. in which were installed sufficient iron grid rheostats to obtain necessary current for the special tests. By means of remote controlled contactors, sections of these grids could be inserted or removed so as to draw whatever current might be called for under each particular test. Behind the gondola was an observation car also furnished by the New York Central R. R. Co. in which were fitted up instruments for indicating the amount of current being collected and the speed at which the train was running. The locomotive is equipped with four bipolar motors with pony guiding axles at the front and rear of each two-axle driving truck. On account of the short length of the cab, the second pantograph was mounted on the gondola to simulate operating conditions. The normal pressure of the pantograph against the trolley wire was between 30 and 35 lb.

Among the visitors who witnessed these tests were consulting engineers from the various parts of the country and representatives from many steam railroads. The following railroads were represented:

Ashtabula Rapid Transit Co.
Baltimore & Ohio R. R.
Boston & Maine R. R.
B., A. & R. P. R.
Buffalo & Lake Erie Traction Co.
Canadian National Rys.
Chesapeake & Ohio Ry.
Chicago Surface Lines
Cleveland Union Terminals Co.
Delaware & Hudson R. R.
Delaware, Lackawanna & Western R. R.
Interborough Rapid Transit Co.
Illinois Central R. R.
Lehigh Valley R. R.
Long Island R. R.
Michigan Central R. R.
New York Central R. R.
New York, New Haven & Hartford R. R.
Norfolk & Western Ry.
Pennsylvania R. R.
Southern Pacific Co.
Third Ave. Railway
United Rys. & Electric Co., Baltimore
Virginian Railway:

The following consulting engineering firms were also represented:

Murray & Flood, N. Y.
Stevens & Wood Co., N. Y.
Stone & Webster, Boston
Archbold Brady, Syracuse
W. D. Spengler, Inc., Cleveland
Jackson & Moreland, Boston
Sargent & Lundy, Chicago
McClellan & Junkersfeld, N. Y.
Gibbs & Hill, N. Y.

Other companies represented included:

The R. D. Nuttall Co., Pittsburgh
The Ohio Brass Co., Mansfield, Ohio
Shields Electric Co., N. Y.
American Locomotive Co., Schenectady
Bridgeport Brass Co., Bridgeport, Conn.
Erie Lighting Co., Erie, Pa.
Dept. of Street Railways, Ashtabula
The Board of Estimate, New York City
McGraw-Hill Co., New York City

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*See G. E. REVIEW, Dec., 1916, p. 1119.

Studies in the Projection of Light

PART VI

THE PARABOLIC MIRROR AND DISK SOURCE OF LIGHT

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

Parts III and IV of this series analyzed the projection characteristics of a parabolic mirror with a spherical source of light, in which latter classification fall the usual bunched types of concentrated incandescent lamp filament. The present article deals similarly with the combination of a parabolic mirror and disk source of light, which latter is regarded as a direct analytical substitute for the plain carbon arc and for the special concentrated incandescent lamp filament the members of which are all mounted in one plane. The formulas and curves furnish a convenient and accurate means of determining the increase of central intensity with distance, the inverse-square region, the testing distance for central intensity, the width of crest of beam, and the width of beam. The treatment of the parabolic mirror with a high-intensity arc as source of light is reserved for a later article.—Editor.

THE DISK AS A SUBSTITUTE FOR THE CRATER OF THE ARC

The crater which is the source of light in all of the more common arcs usually has a depth from one-quarter to one-half its diameter; but, providing the crater is luminous from edge to edge, we are in no wise interested in the depth because the crater is the exact optical equivalent of a flat surface or disk of equal brightness and diameter. The disk thus becomes an idealized source that is in many cases a very close optical counterpart to the actual crater and has the great virtue of being simple to visualize and to treat in a mathematical manner.

It is one of the commonplaces of popular science that carbon when used as a positive electrode comes to a fixed and invariable brilliancy of some 84,000 candles per square inch of crater surface. The general acceptance of this figure as the ultimate in brilliancy of a solid body, such as an electrode, had the effect of stopping for many years the development of the newer types of arc now coming into general use, and, strangely enough, it acted to prevent the complete development of the pure carbon arc itself. Carbon comes to its greatest brilliancy at 3800 deg. A, but the attainment of this temperature depends upon current density, electrode resistance, and the diameter of the electrode; so that we may, and often do, have what seems to be a normal crater without attaining the best results. A classical example of this was the 200-amp. arc (now happily defunct) that gave only one-quarter the theoretical brilliancy and failed to function properly in other ways. One characteristic of this carbon was the formation of an extremely deep crater. The active area of arc contact would center on the core of the electrode and give its best brilliancy (perhaps 30,000 cd. per sq. in.) for a few seconds, then the arc would become conical and hollow, and make contact around the rim of the crater with a brilliancy of half the best value. This arc is mentioned, not because it is of direct practical interest, but because these characteristics are present to some degree in every pure carbon arc. Thus, instead of the carbon crater being of uniform brilliancy from edge to edge, there is always a tendency for either the core or the rim to average a little brighter than the remainder, and we must thus distinguish between the different parts of the crater.

There is some evidence that in a plain carbon electrode of good design the central brilliancy exceeds slightly the limits set by the boiling point of carbon. Two possibilities here suggest themselves. One is the reflection from wall to wall of the crater, thus adding to the radiation brilliancy. It is hardly likely that much could be gained in this way if carbon retains its normal reflection properties at high temperature. The other possibility is that the gas in the crater becomes superheated and being transparent adds its own brilliancy without interfering with the radiation of light from the crater walls. Regardless of the accuracy of this explanation it is a fact that has been noted many times that the center of the projected beam is appreciably stronger than points nearby, whereas the theory of a uniform crater calls for a certain region in the center of the beam where the beam strength is uniform. These variations from absolute uniformity are important to remember in the present discussion of the disk source because while there is a general agreement between theory and test results, there are some discrepancies that can hardly be overlooked or ignored. But when these differences are considered from all points of view and one set of observations are brought into concordance with the general theory, the other test data usually fall directly into line and the geometrical theory here outlined seems to be entirely adequate.

The so-called "high-intensity" or gaseous arc is not only some six times more brilliant than the pure carbon arc, but it has an entirely different crater brilliancy characteristic. In this arc, the main source of light is the heated gas given off by the core and the brilliancy from any angle of view is influenced by the depth of gas as measured in that direction. The edge intensity is only one-sixth the central intensity for here the gas depth is small and the carbon surface is the main source of light.

The pure carbon arc has a crater brilliancy greatly in excess of the brilliancy of the outside walls of the crater, and as a result the beam is fairly sharply and definitely outlined, but the carbon walls of the high-intensity crater are almost as brilliant outside as inside and the beam boundaries are correspondingly hazy. Not only is there thus a lack of a definite boundary at the crater rim, but the luminous gas from the crater spills over the sides and further obliterates any trace of a sharp edge to the light source. These features would seem to make it impracticable to attempt to formulate some simplified substitute for the high-intensity crater such as the uniform disk for the carbon arc and the spherical source used in place of the concentrated incandescent filament.

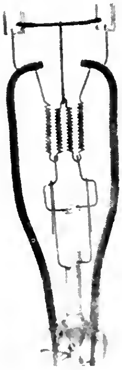

Fig. 47. A Monoplane Filament used for Projection by Condensers in the Motion-picture Industry but Adaptable for Projection by a Mirror

An extension of the theory of the disk luminous on one side only to a disk luminous on both sides will bring many of the high-current incandescent filaments of the monoplane type, Figs. 47 and 48, under the same general theory of the disk.

Fig. 48. A Monoplane Filament Particularly Designed for Projection Purposes. The coils being in multiple can be spaced very close together as the potential difference between adjacent coils is practically zero

It will be shown later that the plain carbon crater may be considered as the general case, and by suitable changes the theory may be extended to the high-intensity arc through the medium of graphical methods. For the present, we can summarize the use of the disk source as a substitute by saying that it is physically a good substitute for the pure carbon arc and for the monoplane incandescent filament; but the high-intensity crater must be treated as a special case which is best handled by applying graphical methods and it seems wise to reserve the high-intensity arc for a separate installment of this series of articles.

The geometrical analysis is always confined to a meridian plane, and if we are considering an incandescent filament, which ordinarily has a rectangular form, the analysis can be carried out in a number of planes, say the two axes of the figure and one diagonal. If it is desired to investigate mathematically the working conditions of a given test, the least favorable condition can usually be discovered and used as a criterion for the entire test.

Increase of Central Intensity with Distance

The fundamental distinction between the spherical source and the disk source is that the latter foreshortens when viewed from a point not on the axis and becomes elliptical in outline. Calling the major axis A and the minor axis B, then at an angle a from the perpendicular to the center of the ellipse, we have

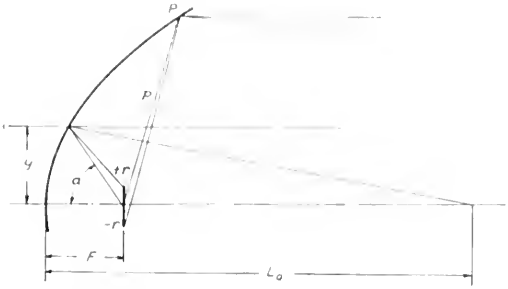

Fig. 49. Diagram Illustrating how the Rays from the +r edge of the Crater Cross the Axis, providing they are reflected from a point on the mirror back of the focal plane, and rays for the −r edge cross the axis when reflected from points in front of the focal plane

$$\frac{B}{A} = \cos a \qquad (93)$$

In Fig. 49 the crater of radius r as seen from the point P is an ellipse of semi-major axis r and semi-minor axis $r \cos a$, and the image of the elemental beam from P has these same proportions with the minor axis set in a radial direction to the axis of the beam. The image touches the axis at a distance L_0 such that

$$\frac{L_0}{y} = \frac{P}{r \cos a}$$

and substituting for y and p their values in terms of F and angle a,

$$L_0 = \frac{2F^2}{r} \times \frac{\tan \frac{a}{2} \sec^2 \frac{a}{2}}{\cos a} \text{ inches} \qquad (94)$$

Two other forms of this equation are sometimes useful:

$$L_0 = \frac{2y^2}{r \sin 2a} \text{ inches} \qquad (95)$$

and $$L_0 = \frac{y\left(F + \frac{y^2}{4F}\right)^2}{r\left(F - \frac{y^2}{4F}\right)} \text{ inches} \qquad (96)$$

As an example, take the case of the three 18-in. mirrors of focal lengths 7.79 in., 4.5 in., and 2.6 in. that have been used in previous illustrations, and let us assume the crater to have a radius of 0.25 in. These three mirrors have angles of 60 deg., 90 deg. and 120 deg. The beginning of the inverse-square region, computed by any of the three last equations, is 750 in. for the 60-deg. mirror and infinity for the 90- and 120-deg. mirrors. Three points about these figures are of interest. The arc with a 60-deg. mirror takes twice the range of the corresponding spherical source to attain full central intensity; the arc with a 90-deg. mirror gives a beam that (in theory at least) never attains full axial intensity at finite distances; and the negative sign found when solving for the 120-deg. mirror indicates a crossing point for the critical ray back of the mirror. This "virtual" point is meaningless for another reason. The 120-deg. mirror has a 90-deg. zone, and therefore it comes under the condition noted above of not having an inverse-square region. The assumption is here made that the source can radiate light to the 120-deg. zone, which is the case when dealing with incandescent lamps with the monoplane filament (see Figs 47 and 48) that entitles them to come under the head of disk radiators.

The beam intensity on the axis is proportional to the area of the mirror that is luminous, and equation (46) is used regardless of the source being a disk or a sphere.

$$I = 4\pi\, Bm\, F^2 \tan^2 \frac{a}{2} \text{ candles} \qquad (46)$$

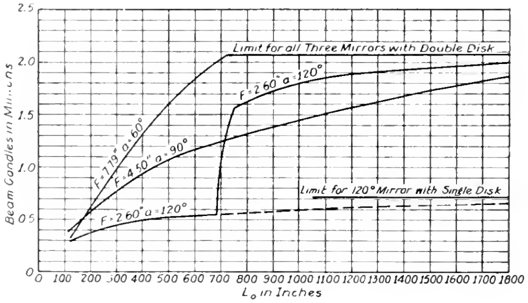

Fig. 50. The Rates of Increase of Beam Intensity for Three Mirrors of Equal Diameters but Different Focal Lengths. Of the three, only the 60-deg. mirror gives a beam that reaches the permanent condition which gives the inverse-square region along the axis. The radius of the source is 0.25 in.

Taking, merely as an example that can be readily compared with the similar one used for the spherical source, a brilliancy B of 10,000 candles per square inch, and a mirror coefficient m of 0.85, the rates of increase are worked out in Fig. 50 for three mirrors with a disk radius of 0.25 in. The beam from the 90-deg. mirror increases rather slowly in intensity along the axis, so that at 720 in. it is only slightly over half as intense as the beam from the 60-deg. mirror. If we imagine the disk to be without thickness then the 90-deg. curve comes tangent to the limiting value of the 60-deg. curve at infinity. The 120-deg. mirror reveals an interesting phenomenon. The first section of the curve, Fig. 50, has a limiting value of 0.72 million candles, because with a disk luminous on the side next to the mirror, the active mirror area would be limited to 90 deg. from the axis, or to one-third of the mirror area. If the disk is equally luminous on the reverse side, an entirely different method of increase is introduced.

The three views of the 120-deg. mirror in Fig. 51 illustrate how the luminous area grows as the observer goes out along the axis of the beam. These views were drawn from the curves of Fig. 52 in which the data were computed by equations (94) and (46). At 360 in. the boundary of the luminous area in the center of the mirror has an angle a of 78 deg. and the mirror beyond this angle is dark. At 720 in. a bright zone has appeared near the edge of the mirror bounded by angles of 106 deg. and 118 deg. as determined by the upper curve in the illustration. The central active zone has grown to 83 deg. as found by the lower curve. At 1080 in. the central zone extends to 85 deg. and the outer zone begins at 97.5 deg. and goes to the edge of the mirror.

Returning to Fig. 50 the first section of the 120-deg. mirror curve is continuous up to 680 in., where a sudden increase in intensity marks the abrupt introduction of the luminous outer zone. The rapid rise of the second section of the curve is broken at 750 in. by this zone reaching the mirror edge, and the slower rise from there on is due to the slow contraction of the dark zone illustrated by the third mirror in Fig. 51. This zone gradually decreases but never entirely disappears.

If equation (94) is plotted as in Fig. 52, it will be found that L_0 reaches infinity when a reaches 90 deg. Above 90 deg., L_0 decreases to a minimum at 111 deg. 30 min. and then increases to infinity at 180 deg. The min-

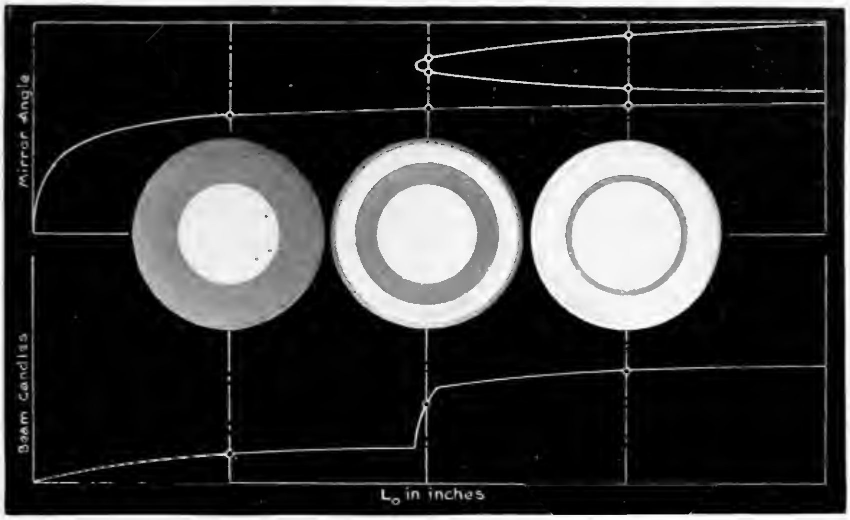

Fig. 51. The manner in which the discontinuous rise of central intensity occurs with a deep mirror and a double disk source is illustrated by the bright zones in these three views of a 120-deg. mirror. The light in the center bright zone comes from the side of the disk facing the mirror, and at short distances the opposite side of the disk does not project light to the axis. As the distance along the axis is increased the beam intensity is suddenly increased due to the appearance of a bright zone on the outer part of the mirror which reflects light from the side of the disk facing outward along the beam. The dark zone between the two active areas decreases as the distance along the axis is increased, but even for an ideal disk of zero thickness the dark zone will never entirely disappear

imum point at 111 deg. 30 min. is independent of either the focal length or the radius of the disk source. The first derivative of (94) when placed equal to zero gives

$$\cos a = -2 \sin \frac{a}{2} \sin \frac{3a}{2} \qquad (97)$$

for a minimum value for L_0 at the above angle.

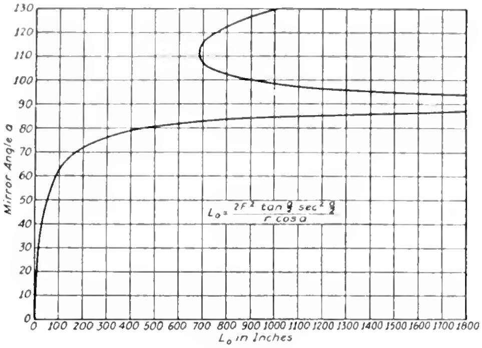

Fig. 52. The plot of the distances at which rays from the various mirror zones first cross the axis of the 120-deg. mirror of Fig. 50 shows that at short range there is a single zone added for each increase of distance, but beyond 680 in. three zones are introduced into the luminous area by each increase of L_0. These zones are on the edge of the central active zone of the middle view in Fig. 51, and on the inner and outer edges of the outer active zone

Three curves for three searchlights are given in Fig. 53. These curves were computed a number of years ago to see if test conditions on the outdoor searchlight range (2300 ft. to test station) were suitable for a series of tests on 60-in. searchlights. This distance was found to be more than sufficient for the plain carbon electrodes having crater diameters of 0.54 in. and 0.81 in and just barely sufficient for the high-intensity electrode. The center of the high-intensity electrode is much brighter than the edge and light from this central portion must reach the axis to give the beam its full central intensity. This arc will be investigated in detail when the graphical methods of computing are explained.

The Inverse-square Region

When a disk source luminous on one or both sides is employed and the mirror angle is less than 90 deg., there is a flat crest to the beam and a region where the law of inverse squares may be used to compute the illumination. But if the mirror subtends an angle greater than 90 deg. from the axis the beam will never reach full intensity because all light reflected from the 90-deg. zone will be parallel to the axis and will not reach it. This, of course, is a theoretical point but it is of considerable importance in bringing out the highly practical fact that an arc with a 90-deg. mirror requires a much greater testing range than any combination previously considered.

A monoplane filament with a mirror of over 90 deg. gives a beam whose intensity rises in a discontinuous manner, as illustrated in Fig. 50, but the approach to the final maximum is probably greatly accelerated by the fact that the filament has considerable thickness along the axis. As a result, there is an inverse-square region at distances only slightly in excess of the second turning point in the curve. As a rule, in testing, the inverse-square region is readily mapped out by walking across the beam at the test distance and observing the angular range over which the entire mirror is active. The results obtained in this way will be influenced by the optical errors in the reflector and other factors, such as the thickness of the filament along the axis and the accuracy of focusing. The theoretical data are therefore only a first approximation to the facts.

The fact that tests on the plain carbon arc do not always show an appreciable flat crest does not necessarily indicate an absence of an inverse-square region, which may be present but concealed by the lack of perfect uniformity of the crater brilliancy.

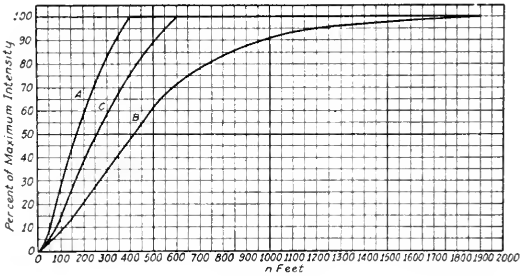

Fig. 53. Curves showing that a 60-deg. mirror with different arcs requires different minimum distances for measuring the full central intensity. Curve *A* shows a plain carbon crater of 0.81 in. dia. with a 60-in. standard mirror requires 400 ft.; a plain carbon crater of 0.54 in. dia. requires 600 ft., as in Curve *C*; but a high-intensity arc of equal diameter, Curve *B*, requires nearly 2000 ft.

Testing Distance for Central Intensity

As a rule those light sources that are classed as disk-formed are readily measured for diameter with considerable accuracy. Thus the crater of the high-intensity arc is consistently within a few tenths of a millimeter of the average value and the monoplane incandescent filament has definite boundaries. The conditions are thus favorable for computing the various beam characteristics from the dimensions of the source except in the case of certain plain carbon arcs that often have oblique craters of irregular outline. This circumstance of greater ease of accurate measurement is fortunate because of the greater (and sometimes inconvenient) distances required for arc testing. We are thus in a position to base our computations on either source dimensions or on the beam width.

Using the observed beam width to compute the testing distance, we get

$$L_0 = \frac{458 \tan a}{C_0\ (1+\cos a)^2} F \qquad (98)$$

This expression differs from equation (50) which is the expression for L_0 with a spherical source by having *tan a* in the numerator in place of *sin a*. Therefore L_0 becomes infinite when $a = 90$ deg. and in the curves of Fig. 54 no greater angle is considered.

Width of Crest of Beam

When the light source is uniformly bright across a diameter the beam has a "crest" or central region in which the intensity is uniform. In nearly every actual searchlight, the crest is not perfectly flat on account of variations in the brightness of the light source. An exploration of the beam from a plain carbon arc gives a definite trace of the edges of the crest, but the intensity on the axis is higher than at these edges. An incandescent filament shows the same departure from theory to about the same degree, which is, of course, due in a large degree to the higher temperature of the central part of the filament.

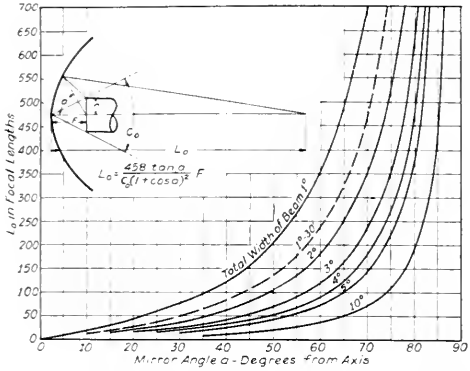

Fig. 54. When the beam diameter is known these curves will indicate the least distance, in focal lengths, at which the central intensity comes to its full maximum value

The beam of the high-intensity arc is most intense in the center and falls off rapidly to either side of the axis so that the plotted curve shows no trace of a flat crest.

The expression for the error E in measuring the crest width has real practical significance even in the case where the crest is not apparent, and equation (54) is a useful guide in selecting test conditions, as will be seen later in investigating the beam formation of a 60-in. high-intensity searchlight at short 2300 ft.) range.

The crest comes to full width only at infinity, and the error at finite distances is

$$E = \frac{L_0}{L} \text{(numeric)} \qquad (54)$$

which indicates that to get fairly correct data on the intensities near the axis the test distance should when possible be five or more times greater than L_0 as computed by equation (94).

Width of Beam

The "width" of beam from a disk source is subject to the same classification as in the spherical source beam. There is the width, at great distances, of angle C_0, and the width C at short distances, and in addition the width according to the 10-per-cent rule.

The limiting angular width C_0 is derived from the spread of light from the center of the mirror.

$$\tan\frac{C_0}{2} = \frac{r}{F} \qquad (99)$$

So long as C_0 is not over 10 deg., we may use the relation

$$C_0 = \frac{114.56\ r}{F} \text{deg.} \qquad (100)$$

as a working approximation.

The curved boundary or envelope of the beam is determined by considering where two rays from an edge of the disk and reflected from adjacent points in a meridian plane meet in the beam. In Fig. 55 two rays from the lower edge of the disk meet at a distance L_e along the axis and at a distance $\frac{W_e}{2}$ from the axis.

$$y_1 + L_e \tan e = y_2 + L_e \tan f$$

$$L_e = \frac{y_2 - y_1}{\tan e - \tan f} \text{inches} \qquad (57)$$

Taking y_1 and y_2 close together so that the difference between them becomes the differential dy, then

$$L_e = \frac{dy}{d\ (\tan e)} \text{inches} \qquad (101)$$

where
$$dy = F\sec^2\frac{a}{2}\,da \qquad (59)$$

and
$$d\,(\tan e) = d\left(\frac{r}{F}\cos a\cos^2\frac{a}{2}\right)$$
$$= -\frac{r}{F}\cos\frac{a}{2}\sin\frac{3a}{2}\,da \qquad (102)$$

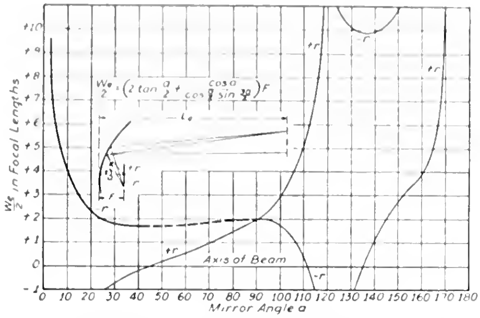

Fig. 55. The width of the beam at any distance is determined by some particular zone within 45 deg. of the axis of the mirror, as shown by the heavy curve; and the region between 45 and 90 deg. (the dotted curve) gives the outline to the inverse-square region. The other mirror zones do not contribute to these important boundaries

Combining (102) and (103) we get for negative (downward) values of r:
$$L_e = \frac{F^2}{r\cos^3\frac{a}{2}\sin\frac{3a}{2}}\text{ inches} \qquad (103)$$
for the distance to the point where the line image of the edge of the disk occurs. The radius of this image from the axis is
$$\frac{W_e}{2} = y_1 + L_e\tan e \qquad (55)$$

The value of *tan e* in terms of F, a, and r is
$$\tan e = \frac{r\cos a}{F\sec^2\frac{a}{2}} \qquad (104)$$
and equation (55) reduces to
$$\frac{W_e}{2} = 2F\tan\frac{a}{2} + L_e\frac{r\cos a\cos^2\frac{a}{2}}{F} \qquad (105)$$
If this equation is further reduced to eliminate L_e, we get the interesting form
$$\frac{W_e}{2} = F\left(2\tan\frac{a}{2} \mp \frac{\cos a}{\cos\frac{a}{2}\sin\frac{3a}{2}}\right)\text{inches.} \qquad (106)$$

It will be noticed that the radius r does not occur in this equation and therefore the width of beam as determined from each section of mirror is independent of the size of the source. What happens is that the image from say the 60-deg. point on the mirror is at a distance 1.7321 F from the axis, but it is closer to the mirror for a large source than for a small one. Therefore, all beams from mirrors of equal angles a are of the same form, and one set of width curves will do for all by simply making the proper change of coördinates.

Equation (106) has been solved and plotted in Fig. 55 for all angles up to 180 deg. There are four branches to the curve, two for the top of the source, $+r$ in Fig. 55, and two for the bottom, $-r$. Not all of these branches are involved in the determination of the beam outline. The ordinates are in terms of the focal length; thus at mirror angle 10 deg. the upper curve has an ordinate of $+4F$ where the + sign signifies distance up from the axis and the $-r$ with which the curve is marked indicates that the lower edge of the source furnishes the light for this boundary. Angle a is always measured upward from the axis. The $-r$ branch goes from plus infinity at 0 deg. to minus infinity (below the axis) at 120 deg. The other part of this $-r$ curve comes from plus infinity at 120 deg. to a minimum at 135 deg. and then returns to plus infinity.

The curve for the upper edge of the source at $+r$ comes from minus infinity at 0 deg. and crosses the $-r$ curve at 90 deg. and then goes to plus infinity. The second section of the $+r$ curve rises from minus infinity at 120 deg. to zero at 135 deg. and then goes to minus infinity at 180 deg.

It is shown in Fig. 56 that only a part of the $-r$ curve between 0 deg. and 45 deg. is directly connected with the outline of the beam. Points from 45 to 90 deg. on the $-r$ curve plus the $+r$ curve from 90 to 120 deg. are used only in connection with the initial straight section of beam before the curved boundaries are encountered.

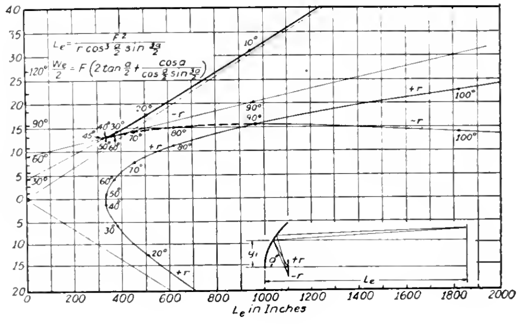

Fig. 56. The relation between the beam width W_e and the distance L_e at which the images from various mirror zones occur is plotted to show that zones zero to 45 deg. furnish the edge rays of the beam and all other images fall within the beam

In Fig. 56 the outline of a beam from a mirror of 7.79 in. focal length with a disk source of 0.25 in. radius is given by the heavy solid lines. On the left of the illustration a scale of degrees is laid out. A straight line from any angle on either the heavy solid line or the heavy dotted line gives the initial straight section of beam edge, and beyond the crossing point the straight line forms the tangent line (tangent at infinity) for the inverse-square region.

If the mirror angle is over 90 deg. there is no inverse-square region and a line through the proper point of the light dotted section of the $+r$ curve is useful only in determining the straight edge of the beam from the mirror out to the curved edge.

At the center of the mirror the linear width of reflected beam is

$$\frac{W_0}{2} = L_e \frac{r}{F} \text{inches} \qquad (64)$$

and at some outer zone at angle a, the width is

$$\frac{W_e}{2} = 2F \tan \frac{a}{2} + L_e \frac{r \cos a \cos^2 \frac{a}{2}}{F} \text{inches} \qquad (105)$$

The excess width of $\frac{W_e}{2}$ over $\frac{W_0}{2}$ is

$$E = \cos^2 \frac{a}{2}\left(2 \sin \frac{a}{2} \sin \frac{3a}{2} + \cos a\right) - 1 \text{ (numeric)} \qquad (107)$$

and from the absence of both F and r the excess is quite evidently dependent only upon the angle a. The distance along the axis at which the measured excess corresponding to angle a occurs is dependent upon F^2 and r as may be seen in equation (102) for L_e. The excess width is a maximum (20.9 per cent) at 45 deg. and in this it differs from the beam from the spherical source which has a maximum of 12.5 per cent at 60 deg.

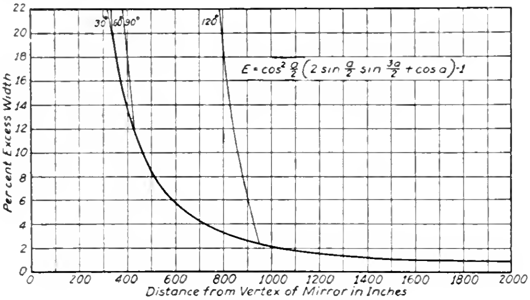

Fig. 57. The beam width at extreme ranges is determined solely by the exact center of the mirror, but at working ranges other zones of the mirror produce a beam of greater width. At short range, rays from the edge of the mirror form temporary false beam edges that are greatly in excess of the true beam width

One visible effect of the low angle at which the maximum occurs is the sharp spindle or neck in the beam from an arc lamp. The mirrors used with arcs nearly always have an angle of 60 deg. and the initial edge ray of the beam intersects the curved boundary at an appreciable angle as illustrated in an exaggerated manner in Fig. 56.

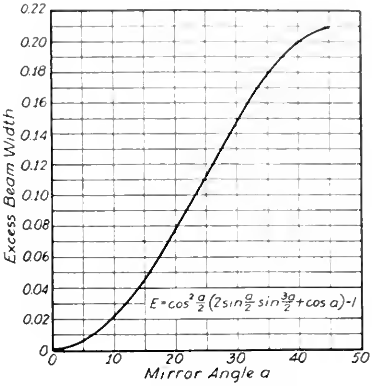

Fig. 58. The excess of beam width at finite distances over the final beam width is solely a function of the angle of the mirror zones; the value of the excess is not influenced by the relative size of the source, although the distance at which some particular excess width occurs is dependent upon the ratio of r to F

The errors arising from computing or testing the beam of a 7.79 in. focus mirror at ranges so short as to encounter the initial straight boundary from the edge of the mirror are shown by the branches from the heavy curve in Fig. 57. For this particular case distances under 1000 in. are evidently best avoided.

The general relation between the excess width and mirror angle is given in Fig. 58. The data of this curve can be applied to any case by solving for L_e independently, using the proper values for focal length, radius of source, and mirror angle a. The data so obtained, when plotted, give a curve similar to that of Fig. 57. A comparison of this curve with Fig. 30* shows that while the disk source reaches higher errors for given regions on the mirror, the errors at any given range along the axis of the beam is about half. Thus at 1000 in. the spherical source gives an excess beam width of 6 per cent, while the disk source at the same distance gives an excess of only 2 per cent. We can therefore conclude that, in general, the arc searchlight can be tested for beam width at considerably shorter distances than the corresponding spherical shaped incandescent filament.

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* See Part IV of this series, GENERAL ELECTRIC REVIEW, May, 1923.

The Electron in Chemistry

PART II(A)

By Sir Joseph John Thomson

Master of Trinity College, Cambridge, England

In our August issue we published the first of this series of lectures. The second lecture, published in full in the June issue of the Journal of the Franklin Institute, is so long that we divide it. Accordingly in this issue we print Part II (A) dealing with The Combination of Atoms to Form Molecules; Four-electron Atoms, Combination of Different Elements, Chemical Compounds; Polar Molecules; Physical Test for Polar Molecules and Arrangement of Electrons in Octets. In our October issue we purpose printing Part II (B) which will include Disposition of the Electrons in Typical Compounds; Connection Between Chemical Constitution and Chemical Properties; Residual Affinity, Molecular Compounds, Werner's Co-ordination Numbers and Electrolytic Dissociation.—Editor.

The Combination of Atoms to Form Molecules

We shall begin by considering molecules in the gaseous state, where each molecule is separated so far from its neighbors that it may be regarded as an individual and not as merely forming a brick in a much larger structure. Indeed, the term molecule when applied to the solid state is quite ambiguous without further definition; for example, from many points of view we can consider quite legitimately the whole of a large crystal as forming a single molecule. It is natural to expect that when the atoms are crowded together as in a solid, where each atom may come under the influence of a large number of neighbors, the arrangement of the electrons relatively to the atom may differ substantially from that in a gaseous molecule.

Let us begin with the simplest case, that of the union of two similar atoms each containing one electron. We see that if the atoms and electrons are arranged as in Fig. 2, where A and B are the atoms and α and β the electrons, the mutual repulsion of the electrons may be balanced by the attraction of the positive charges on the electrons; and the mutual repulsions of the similarly electrified atoms by the attractions of the electrons. Thus we may regard the electrons in the atom as acting like hooks by which one atom gets coupled up with another. As the atoms are held together by the attraction of the pair of electrons α, β, the presence of two electrons between the atoms may be taken as the physical interpretation of what is called a bond by chemists. In this example and in general, two electrons go to each bond. There are, however, cases such as that of a positively electrified molecule of hydrogen (so frequently detected in positive-ray photographs) where a single electron is able to bind two atoms together. The arrangement being that represented in Fig. 3.

The dimensions and shape of the parallelogram represented in Fig. 2 will depend on the law of force between two positive charges at atomic distances as well as upon that between a positive charge and an electron. If $e^2\phi\left(\frac{c}{r}\right)$ is the attraction between a positive charge e and an electron with equal charge separated by a distance r and $e^2\psi\left(\frac{c^1}{r}\right)$ the repulsion between two positive charges at a distance r, then if $A\alpha = r$ and $< A\alpha\beta = \delta$, we have for equilibrium

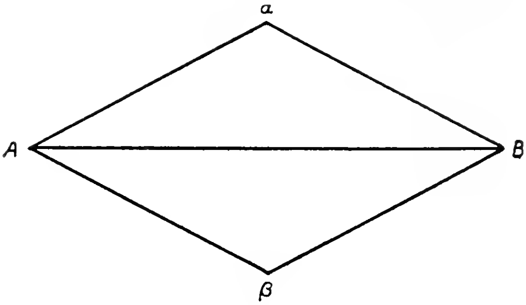

Fig. 2

$$2^2e\phi\left(\frac{c}{r}\right)\cos\delta = \frac{e^2}{4r^2\cos^2\delta} \qquad (25)$$

$$2e^2\phi\left(\frac{c}{r}\right)\sin\delta = e^2\psi\left(\frac{c^1}{2r\sin\delta}\right)$$

Though the distance of an electron from its atom will obviously be not quite the same in the molecule as in the atom, we should expect that the differences would not be very large. For if they were, work would have to be done at some stage in the act of combination comparable with that required to ionize an atom, as this work is much greater than the equivalent of the heat developed by the union of the atoms to form a molecule we could not expect atoms under these conditions to combine to form molecules except in the presence of a very efficient catalyst.

Let us now pass to the case where each of the atoms contains two electrons. If only one pair of electrons is used up in uniting the atoms, the arrangement would be that represented in Fig. 4, where the Greek letters represent the electron. In the language of chemists this would be expressed by saying that the atoms were united by a single bond and the molecule would be expressed by the formula $-A-B-$. The electrons α' and β' would enable this molecule to link up with other molecules so that it would not be saturated. If, however, all four electrons are used in coupling up the atom, they will be at the corners of a square bisecting AB at right angles.

The system of four electrons instead of two between the positively electrified atoms may be regarded as the physical equivalent of what the chemists call a double bond. Inasmuch as the equilibrium of four electrons in one plane, when their displacements are not confined to that plane, requires very strong restoring forces to make it stable, we should not expect the double bond to be permanent when the positive charges which exert the restoring force are as small as in this case, where their sum is only equal to the sum of the charges on the four electrons.

For the union of two tri-electron atoms, if all the electrons were used to couple up the atoms, there would be a hexagonal ring of electrons in a plane bisecting AB at right angles; as this ring requires a greater positive charge than that of three units on each side to keep it in stable equilibrium it would be unstable. The most probable arrangement of the electrons is the octahedral one shown in Fig. 5 with four electrons between the atoms and two on the line AB; this would be represented symbolically by the formula $-A=B-$. The end electrons would enable it to bind other atoms so that the molecule would not be saturated.

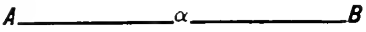

Fig. 3

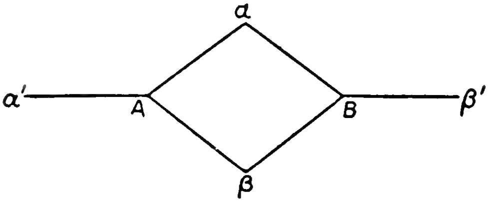

Fig. 4

Four-electron Atoms

These may form a molecule in which the electrons are as represented in Fig. 6, four electrons are between AB and the other four form two pairs beyond the extremities of the line AB.

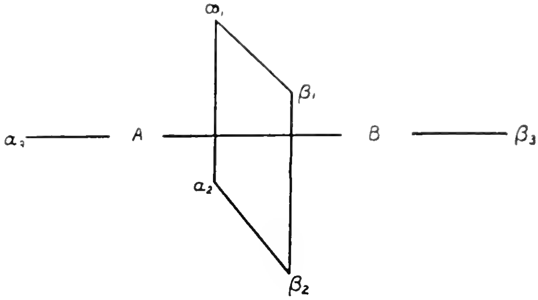

Fig. 5

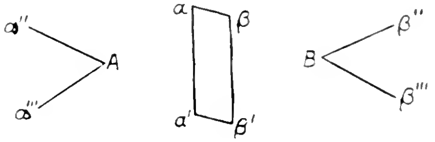

Fig. 6

A peculiarity of the arrangement in Fig. 6 is that the molecule has four free electrons the same as the original atom, thus other atoms can be coupled up with the molecule, and we might have a chain of atoms, each atom being at the center of a parallelipiped of eight electrons. We can show that a long chain of such atoms would be unstable, but it is evident that the four-electron atom is one peculiarly suited for forming complexes containing several atoms. The carbon atom has four electrons in its outer layer and thus carbon atoms would have a great tendency to unite with each other. It is this tendency that is responsible for the Science of Organic Chemistry. I may point out in passing that we can obtain from the study of positive rays direct evidence of the coalescence of carbon atoms. For on a positive-ray photograph of benzene I found lines corresponding to C_1. C_2, C_3, C_4, C_5, where C_1 represents a carbon atom; C_2, a carbon molecule; C_3, a carbon triplet, and so on.

The form we have suggested for the electrons in the molecule of atoms of this type is represented symbolically by the formula

— *A* - *B* — When we come to the case of five-electron atoms we have to introduce new considerations. We have seen that eight is the maximum number of electrons which can be in stable equilibrium in a single layer under the action of positive charges whose aggregate cannot exceed the total charges carried by the electrons. With a five-electron atom we have ten electrons in the molecule, while the aggregate positive charge, in the molecule, is also ten, which is not sufficient to keep the ten electrons in stable equilibrium if spread over a single layer. A simple way of arranging the electrons is shown in Fig. 7. Midway between the positive charges are six electrons which keep the atoms together, four of them at the corners of a square forming the normal double bond, while two others are inside the square.

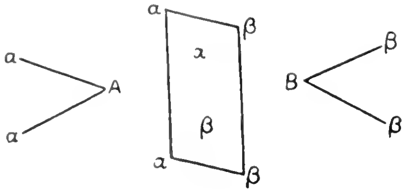

Fig. 7

The remaining four electrons are arranged in pairs beyond the atoms *A*, *B*, respectively. Thus we have eight electrons surrounding two atoms and two electrons. The arrangement is somewhat like that suggested for the carbon molecule with the addition of two electrons near the center of the molecule.

When each of the atoms contains six electrons the arrangement is as follows: There are four electrons forming the normal double bond between the atoms, and two other sets of four, one set beyond *A*, the other beyond *B*. Thus each of the two atoms may be regarded as being inside an octet of electrons, the two octets having four electrons in common. When each of the atoms contains seven electrons, we have fourteen electrons at our disposal. These may be arranged so that two of them form a single bond between the atoms while the remainder complete two octets with two electrons common to both, as is represented in Fig. 8. This, though a very symmetrical arrangement, is not the only conceivable one. For when the positive charges are large, as they are in this case, they might hold four or even more electrons in stable equilibrium, even though the electrons were very close together. Thus suppose there were a double instead of a single bond between the atoms, this would account for four electrons, leaving ten to be distributed outside. If these were distributed symmetrically, there would be five around each atom, so that each atom would be the center of a layer containing nine electrons, four coming from the double bond and five from those left over after the double bond has been provided for. Now nine electrons could not be in equilibrium if equally distributed under a central charge of seven, but if four of them are held close together in stable equilibrium under two positive charges, it is possible that there may be room for the other five to be so far apart that they can be kept in stable equilibrium by a positive charge of seven units.

It will be noticed that the molecules formed by the union of two atoms, each of which contains less than five electrons, have free electrons which are available for linking up with other molecules. The one-electron atoms could form chains as in Fig. 9. Thus the process of aggregation is not exhausted by the formation of the molecule; these molecules will form further aggregations and thus tend to get into the solid or liquid state. On the other hand, the molecules formed by atoms with five or more electrons form saturated systems and will not tend to aggregate further. This agrees with the properties of the elements; for Li, Be, Bo, and C, whose atoms contain less than five electrons, are solids, while N, O, F and Ne, whose atoms contain five or more electrons, are gases.

From the consideration of the arrangements of the electrons in different molecules, we see that for the atoms containing four and five electrons we can regard the electrons in the molecule as roughly distributed over a single layer not very far from spherical; when, however, we reach the six-electron atom the

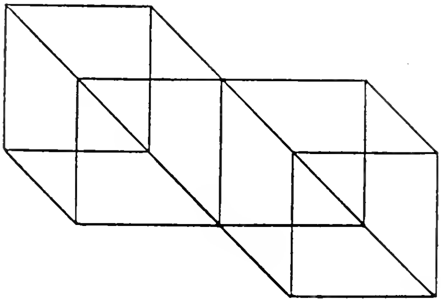

Fig. 8

electrons in the molecule form two cells, and a surface which would contain them all would have to be very elongated. We get some confirmation of this result from the study of the scattering of polarized light by gases. The theory of such scattering shows that the light scattered by a single electron in a direction at right angles to the incident beam is completely polarized and can be extinguished by a Nicol prism. The same thing is true when the light is scattered by a perfectly symmetrical body such as a sphere. If the scattering body is not perfectly symmetrical, if, for example, it is elliptical instead of spherical, the scattered light is never completely polarized and therefore cannot be entirely quenched by a Nicol. The ratio of the minimum to the maximum intensity of the light seen through a Nicol would be zero for a spherical body, but would be finite for an ellipsoid and would increase with the ellipticity. The value of this ratio may be taken as an indication of the deviation of the scattering body from sphericity. The scattering of light by molecules is due to the electrons in the molecules; we should expect that an arrangement of electrons in one shell would approach more closely to the spherical arrangement than an arrangement in two cells, and that two cells would approximate to the spherical more closely than three. Thus the ratio of the minimum to the maximum intensity of the scattered light should increase with the number of cells. Lord Rayleigh[8] has determined the value of this ratio for several gases with the results given in the following table:

Gas	Ratio Expressed as a Percentage
Argon	0.46
Hydrogen	3.83
Nitrogen	4.06
Oxygen	9.4
Carbon Dioxide	11.7
Nitrons Oxide	15.4

We see how small this ratio is for the symmetrical distribution of electrons round the argon atom. A striking feature of the table is the great jump between nitrogen and oxygen. We have seen that the passage from nitrogen corresponds to the transition from an arrangement of the electrons in one cell to one in two cells, and thus involves a great loss in symmetry. The electrons in carbon dioxide and nitrous oxide require three cells for their arrangement and thus are less symmetrical than those in the oxygen molecule.

Fig. 9

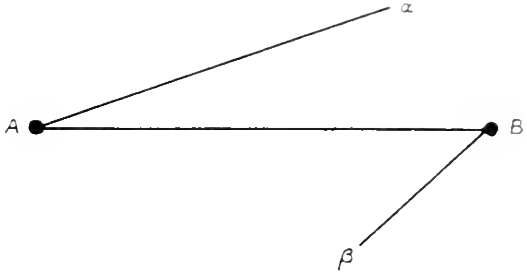

Fig. 10

Combination of Different Elements, Chemical Compounds

We may apply considerations similar to those we used to explain the formation of molecules of an element by the union of two similar atoms to the union of two different atoms to form the molecule of a compound.

Let us consider, for example, the union of a seven-electron atom with a one-electron atom. Suppose that A is the center of the first atom, B, that of the second, see Fig. 10.

Let α be an electron in the first atom, β one in the second. Then if B and β place themselves somewhat as in the figure, the attractions the two electrons exert on A, B may keep these together in spite of their mutual repulsions, while the electrons are kept in equilibrium by the attraction upon them of the atoms A and B. The addition of β to the seven electrons already round A will raise the number in the outer layer of A to eight. Now suppose we attempt to attach another atom β' to A, this would introduce another electron into the outer layer round A, raising the number in this layer to nine. We have seen, however, that nine electrons in one layer cannot be kept in stable equilibrium by a positive charge of nine units; in this case nine units are all we have at our disposal and two of these are outside the layer. The outside ones will make the arrangement of electrons more stable than it would be in their absence. They will not, however, increase the stability more than they would if they were inside, and even in that case they could not make the arrangement stable. Thus A cannot hold a second atom of the type B, so that the compound AB_2 is impossible and that represented by AB is saturated. Thus, if B with

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[8] *Proc. Roy. Soc.*, *98*, p. 57

its one electron is taken as the type of a monovalent atom, like hydrogen, *A* with its seven electrons would also be monovalent, and would in this respect act like fluorine. The electrons in the molecule *HF* would form a layer round the center of the fluorine atom with the positive part of the hydrogen atom outside. Let us now suppose that *A* is a six instead of a seven-electron atom and let an atom of *B* get attached to it in the way we have supposed. This will raise the number of electrons in the layer round *A* to seven, so another atom can be attached before the number of electrons in the outer layer is raised to eight and the limit of stability reached. Thus *A* could form the unsaturated compound *AB* and the saturated one, AB_2, but *A* could not combine with more than two atoms of *B*. Thus *A* with its six electrons would behave like the atom of a divalent element, say oxygen.

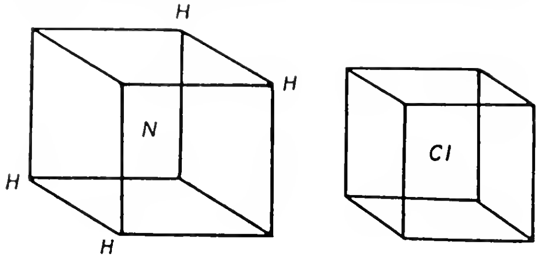

Fig. 11

In a similar way we see that if *A* contained five electrons it would form the unsaturated compounds *AB* and AB_2 and the saturated one AB_3. Thus *A* would behave like a trivalent element, nitrogen.

In this way we see that when *A* acts as the center round which the layer of electrons is arranged, it behaves like an element whose valency is equal to (8–number of electrons in the outer layer of the atom *A*).

There is, however, another way in which the atoms might combine, in this *A*, instead of receiving electrons from other atoms, might give up its electrons to help to form a layer round another atom. Take, for example, a two-electron atom *B*, by using one of its electrons it can attach itself to a seven-electron atom and still have one electron free. It can use this free electron to bind itself to another seven-electron atom and thus form the compound BF_2, where *F* represents an atom of such an element as fluorine. Thus in this type of compound the atom with its two electrons would behave like a divalent element. A three-electron atom would be able to bind three atoms of fluorine and so on. In this type of compound the atom under consideration is acting, so to speak, as a giver and not as a receiver of electrons. The valency of the atom when acting in this way is equal to the number of its electrons. The electron theory thus, as I pointed out long ago,[9] leads in a very natural manner to an explanation of valency and it suggests conclusions very similar to those advanced by Abegg and Bödlander,[10] who ascribed to each element two valencies according as it was combined with a more electronegative or more electropositive element. The sum of the two valencies always being eight. We have in some of the elements notable examples of two valencies; take nitrogen as an example, whose atoms contain five electrons in the outer layer. If this combines with hydrogen, three atoms of hydrogen will saturate it, as they will bring the number of electrons in the layer round the nitrogen up to eight, the limiting number, thus in the compound NH_3, the nitrogen behaves as a trivalent element. But suppose that instead of combining with a hydrogen atom it combines with a chlorine one, which we assume to have seven electrons in the outer layer. One of the electrons from the nitrogen atom might join the layer round the chlorine one, bringing the number of electrons in the latter up to eight, and leaving four in the nitrogen atom. These four electrons can link up with four hydrogen atoms which will bring the number of electrons in the layer round the nitrogen atom up to eight, the limiting number. We thus get the compound NH_4Cl. The arrangement of the electrons being as represented in Fig. 11. As the chlorine nucleus has a positive charge of seven and is surrounded by a layer containing eight electrons, the atom Cl in this compound has a unit negative charge. Since there is a positive charge of five on the nitrogen nucelus and one of four on the four hydrogen atoms, there are nine positive charges on the system NH_4, which contains eight electrons; there is thus a balance of one positive charge on the system represented by NH_4, so that NH_4 Cl would, when electrolyzed, give NH_4 and Cl as ions.

Again each of the five electrons of the nitrogen atom might go off to complete the tale of eight electrons round each of five chlorine atoms forming the compound NCl_5; though this substance does not seem to have

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[9] *Phil. Mag.* [6], *27*, p. 757 (1914)

[10] *Zeit. Anorg. Chem.*, *20*, p. 453 (1899); *30*, p. 330 (1904)

been prepared, the corresponding compound PCl_5 is well known. The oxygen atom containing six electrons might attach itself to six atoms of chlorine and so be apparently hexavalent, as sulphur is in the remarkable compounds SF_6, discovered by Moissan.

Carbon having four electrons in the outer layer has the same valency $4 = 8 - 4$, whether it is acting in either of the above-mentioned ways, hence the compounds CH_4, CCl_4. The kind of union between atoms which we have been considering requires two electrons to effect the bond, hence since we cannot have more than eight electrons round a central atom, four is the maximum number of atoms which can be bound by a single atom. There are in fact very few exceptions to this rule, the most conspicuous are the chlorides of some of the elements which have very variable valencies, such as $UrCl_5$, WCl_5, $MoCl_5$, which will be considered later.

Thus the considerations we have been discussing give a physical basis for the theory of valency in the extended form given by Abegg. The electron theory, however, is much more general than the laws of valency and points to the existence of compounds which are not in accordance with these laws. The electron theory states that any distribution of atoms and electrons in stable equilibrium is a possible compound and will be saturated provided that each electronegative atom is surrounded by a layer containing eight electrons.

Let us consider, as an example, carbon monoxide, CO; this according to valency laws, is an unsaturated compound, the gas is, however, remarkably inert and only liquefied with great difficulty, so that its physical properties give no support to the view that it is a highly unsaturated gas. In CO there are ten electrons to be arranged the same as in N_2, and we may therefore expect that a similar arrangement to that represented in Fig. 7 would furnish a stable and permanent molecule. As the positive charge on the carbon is not the same as that on the oxygen, the cell will not be so symmetrical as that of the nitrogen molecule. It is interesting to note that, as Langmuir has pointed out, some of the physical properties of CO are very similar to those of N_2. If this is the constitution of the molecule of CO, it explains why we do not get CH_2 as a saturated substance, as the ordinary valency theory would lead us to expect. There are only six available electrons in CH_2 and these are insufficient to produce a completely saturated layer. It is important to point out that we distinguish between the molecule of carbon monoxide and that of the carbonyl radicle CO.

In the latter we suppose that two out of the four electrons of the carbon atom have gone to unite it with the oxygen and to make up the eight electrons required to form the layer round the oxygen atom, while the other two are free to join up with other electrons. Thus while the molecule of CO is represented by Fig. 7, that of the carbonyl radicle is represented by Fig. 12.

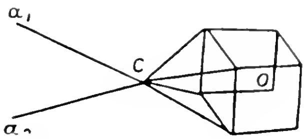

Fig. 12

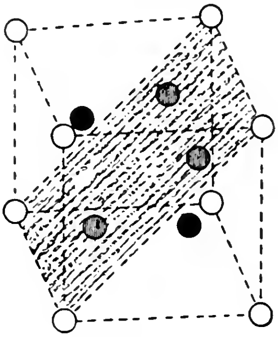

Fig. 13

Another molecule which may have a somewhat similar constitution to that of CO is NO, Fig. 13. The molecule contains eleven electrons, if we take eight of these to form the outer layer we are left with three, these by taking up positions between the atoms of nitrogen and oxygen inside the outer layer may help to keep these atoms together. The molecule of nitrogen monoxide is not the only form in which the combination NO occurs; it can also exist as the radicle NO, and just as we suppose the carbonyl radicle to have a different configuration from that of the molecule CO, so we suppose that the radicle NO has a configuration in which eight electrons form a cell round the oxygen, the nitrogen atom is surrounded by a layer of seven electrons made up of the three electrons left over after two have been supplied to the oxygen octet; the other four form part of the layer round the oxygen atom. The layer round the nitrogen requires another electron to saturate it and will thus act like a univalent atom. The three electrons left over from the five nitrogen electrons after two have been used to saturate the cell round the oxygen atom might be used to bind three hydrogen ions and thus it is possible that under certain circumstances this radicle might be trivalent.

Nitrogen monoxide is an example of the rare type of molecule where the number of electrons in the molecule is odd. Other examples of this type are NO_2 and ClO_2. If we suppose that for stable substances an octet of electrons is formed round each of the heavier atoms in the molecule, then if the number of electrons is odd, some of these octets must have an odd number of electrons, either one or three, in common. If we suppose the octets are cubes, they could not have three electrons in common, though they could have one, the two cubes having a corner in common. If, however, the electrons are arranged in twisted cubes instead of the ordinary cubes, two octets might have 1, 2, 3 or 4 electrons in common, since twisted cubes have triangular as well as square faces and thus we might have molecules containing an odd number of electrons with a less exiguous connection between the atoms than that furnished by a single corner common to two octets. The three-electron contact would account for the existence of a saturated compound with the formula ClO_2. We have here nineteen electrons and these might be accommodated in three octets if there was one double contact and one triple one.

Another problem in which the triple contact might come in, is the well-worn one of the benzene ring. In benzene C_6H_6 we have thirty electrons which have to be arranged in octets round six carbon atoms. The simplest and most symmetrical way of doing this is to have the six cells in contact round a ring with a three-fold contact between each two. As two opposite triangular faces of the twisted cube are inclined to each other, this could be done without introducing much strain into the system. Models have been made by two of my students on this principle of a benzene ring and also of a naphthalene one. With this arrangement we have complete symmetry, and it is analogous to the Armstrong and Bayer or central theory of the benzene ring. The configuration corresponding to Kekules' conception of the constitution of the benzene ring would consist of three sets of pairs of cells, the cells in one pair having four-fold contact with each other, but only double contact with a cell in a neighboring pair.

The three-contact view leads to results with regard to the constitution of additional compounds of benzene and the halogens which are in harmony with experience.

The process which we have just been describing by which two atoms A, B are united into a molecule AB, of a compound may be regarded as consisting in one or more of the electrons in the outer layer of A becoming a member of the outer layer of B. This is equivalent to one of the electrons in the outer layer of B becoming a member of the outer layer of A. Thus each atom lends electrons to the other to enable it to fill up its outer layer; the atoms share their electrons for this purpose and the electrons which they have in common tend to hold the two atoms together. I think it is desirable to emphasize this aspect of the question, to regard the union of the two electrons as a sharing of their electrons rather than as the robbery of one atom of the electron belonging to another. I doubt if there is any very large change produced in gaseous compounds by chemical combination in the distance of an electron from the center of the atom to which it originally belonged. I do not mean that the distance remains unaltered, but only that there is no such change in distance as would warrant our saying that the electron was bound to B before combination and was free afterwards. To tear electrons from an atom requires a much larger amount of work than to separate a molecule into uncharged atoms, and though there may be a redistribution of the electric charges on the molecule, there is nothing which can fairly be described as ionization. Thus to take a specific example we regard the constitution of a molecule of HF as consisting of a unit positive charge H outside an outer layer of eight electrons surrounding the fluorine atom with its positive charge of seven units, and though we may legitimately describe the molecule as consisting of a positively charged hydrogen atom and a negatively charged fluorine one, it does not follow, if the

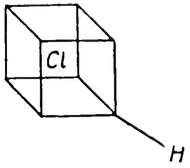

Fig. 14

molecule were dissociated by a rise in temperature, that the product of dissociation would be a positively charged hydrogen atom and a negatively charged fluorine one. It would take much less energy to detach the positive hydrogen atom plus an electron than the positively charged hydrogen atom alone, so that the probable result of the dissociation would be a neutral hydrogen atom and a neutral fluorine one. This would not necessarily be the case if the dissociation were effected by a high-speed positive ray with an energy corresponding to many thousand volts, for then the hydrogen atom could receive energy far more than sufficient to detach it from the negative electron. The result to which we have been led that dissociation would yield neutral atoms is in accordance with experience, for we do not find that chemical changes in gases produced by a rise in temperature are accompanied by a rise in electrical conductivity unless the gases are in contact with hot metals, and in this case the increase in conductivity may be explained by thermionic effects. The absence of electrical conductivity in several cases of chemical action at moderate temperatures was investigated by Bloch,[11] who showed that the dissociation of arseniuretted hydrogen which takes place at low temperatures is not accompanied by any increase in the electrical conductivity. He also showed that many chemical actions which go on at low temperatures such as the oxidation of nitric oxide, the action of chlorine on arsenic, the oxidation of ether vapors, have little or no effect on the conductivity.

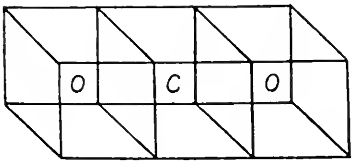

Fig. 15

Polar Molecules

Though in the gaseous molecule we have not ionization in the sense that the atoms of the molecules are free to move in opposite directions under the action of an external electric force, yet the disposition of the electric charges may be such that the molecules would tend to set in a definite direction under the action of such an electric force. The center of the positive charges does not always coincide with that of the negative ones, so the molecule may have a definite electric moment. It is only in some type of molecules that this electric moment has a finite value. Thus in the symmetrical molecule formed by the union of two atoms of the same kind the centers of the positive and negative electric charges coincide and the molecule has no electrical moment. Whereas in a molecule like HCl, where the positive charge is outside the octet as in Fig. 14, the molecule has evidently a finite electric moment.

In other compounds such as CO_2, of which the arrangement is that in Fig. 15, there is complete symmetry. Thus, as I pointed out some years ago,[12] molecules may be divided into two types: (*a*) Polar, those having a finite electric moment; (*b*) Non-polar, those for which the electrical moment vanishes.

These two types will have very different properties. If the molecule has a finite electrical moment, it will give rise to an electric field whose intensity will vary inversely as the cube of the distance, while if the electric moment vanishes the force due to the molecule will vary inversely as some higher power of the distance and will thus die away much more rapidly than the forces due to a polar molecule; the latter will have a more extensive stray field and will attract and be attracted by a much larger number of other molecules.

Physical Test for Polar Molecules

We shall first describe a test based on physical principles by which we can separate the polar from the non-polar molecule and then see whether the molecules so separated show marked difference in their chemical properties.

The physical method for determining whether the molecule has a finite moment or not is the determination of the specific inductive capacity of the substance formed by the molecules, and if possible when the substance is in the gaseous state. The molecule with a finite moment will tend to set in a definite direction under the electric field, and this setting will contribute to the specific inductive capacity of the gas, hence such molecules will tend to give an abnormally high value to the specific inductive capacity. Again, since this setting of the molecule involves the rotation of the molecule as a whole, these will move so sluggishly that they will not be affected by vibrations as rapidly as those of light waves in the visible spectrum.

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[11] *Ann. de Chimie et de Physique*, 22, pp. 370, 441; 23, p. 28.
[12] *Phil. Mag.*, 27, p. 757 (1914)

Hence these molecules will not affect the refractive index in the visible spectrum while they will affect the specific inductive capacity. We should expect, therefore, that the substances formed by such molecules would depart widely from Maxwell's law that the square of the refractive index is equal to the specific inductive capacity. Again, since the setting of the molecules under the electric field will be hampered by the collisions with other molecules and as these collisions are more numerous and vigorous at high temperatures than at low, the specific inductive capacities of these substances will be affected by temperature and will diminish as the temperature increases. Bädeker[13] has determined the specific inductive capacities of many gases at varying temperatures, and it appears from his results that some of these gases, such, for example, as H_2O, NH_3, HCl, CH_3OH, exhibit all these characteristics, they have specific inductive capacities which are much greater than the square of the refractive index and which diminish as the temperature increases.

TABLE I

Compounds Which Have a Finite Electrical Moment

H_2O	CH_3OH	SO_2	CH_3Cl
NH_3	CH_2OH	HCl	$CHCl_3$(slight)

Taking this as the criterion, we can find whether the molecules have or have not finite electrical moments and in the following tables, derived from measurements made by Bädeker and other observers, of the specific inductive capacity of gases, various compounds are placed in one or other of two classes.

This list shows that the physical test we have applied separates the substances into two types which have great differences in their chemical properties. In the first type we have substances like water and alcohol which are good ionizers of salts or acids dissolved in them.

The substances in the first table are also those which, like water, ammonia, and alcohol, are conspicuous in forming complex compounds with other salts, such as the hydrates, alcoholates, ammoniates. Another property which differentiates the substances in Table I from those in Table II is that of giving electrification by bubbling. When air or other gases bubble through some liquids, *e.g.*, water, alcohol, acetone, the gas when it emerges is found to be ionized, *i.e.*, mixed with positive and negative ions. Little, if any, electrification is found when a gas bubbles through a liquid like paraffin oil or benzene. This is shown very clearly by the experiments of Bloch.[14] Liquids of the first type show electrification by bubbling, those of the second do not.

Molecules which contain the hydroxyl radicle OH, such as H_2O, CH_3OH, C_2H_5OH, are usually polar; other organic radicles, such as COOH, CO, CN, NO_2, also make the molecules of which they form a part polar. As the attraction of polar molecules extends over a much wider field than that of non-polar ones, we can understand why, though the hydrogen in saturated non-polar molecules such as CH_4, C_2H_6 is not oxydized by weak solutions of sulphuric acid or bichromate of potash, the hydrogen in polar molecules such as CHO_3H, CH_2O (formaldehyde), CHOOH, is oxydized under the same conditions.

TABLE II

Compounds Which Have Not a Finite Electrical Moment

H_2	CO_2	He	C_6H_6
O_2	CS_2	Cl_2	CH_4
N_2	CCl_4	CO	N_2O

The fact that the polar molecule must be unsymmetrical gives us some information about the configuration of the electrons. One of the most interesting cases is that of water, which is conspicuous above all molecules for the possession of an electrical moment. Our first impression is that the structure of the water molecule should be that represented by Fig. 16, where the two hydrogen atoms are symmetrically placed with respect to the center of the oxygen atom and the electrons are symmetrically distributed round the line joining the hydrogen atoms. This, however, cannot be right, for it would correspond to a molecule having no electrical moment. If the octet of electrons round the oxygen atom were situated at the corners of a cube, then there could be no question that a symmetrical arrangement of the hydrogen atoms with these atoms, respectively, attached to two electrons at the opposite ends of a diameter would be the position of equilibrium and this would correspond to a system having no electrical moment. If, however, the electrons were arranged at the corners of a twisted cube, no two electrons would be at opposite extremities of a diameter. Thus, if the positive atoms were attached to two electrons the system would be unsymmetrical and would have an electrical moment. Thus the electrical and chemical properties support the view that the electrons in the octet are at the corners of a twisted cube. The symmetrical

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[13] *Zeit. für Physik. Chem.*, *36*, p. 305

[14] *Ann. de Chimie et de Physique*, *23*, p. 28 (1911)

position for the hydrogen atoms would, with the twisted cube, be when the positive hydrogen atoms are on the axis through the center at right angles to the square faces. On this axis the positive atoms cannot be at a distance from the nearest electron less than half the diagonal of a square face. This distance is greater than would be necessary if the hydrogen atoms were placed close to the corners of the octet. This increase of distance would correspond to an increase of potential energy which might make the arrangement unstable. If would appear from these considerations that there may be more than one form of water. Thus the two hydrogens might be joined (*a*) to two electrons on the same square face or (*b*) one of the hydrogens might be joined to an electron on one square face and the other hydrogen to an electron on the other. Similar considerations would apply to the hydroxides of the alkali metals, but we should hardly expect the want of symmetry in these to be as pronounced as in hydrogen for the reason that the radius of say an atom of sodium is greater than that of one of hydrogen, so that these atoms might be able to get into the symmetrical positions without their distance from the nearest electron being increased much beyond that between the atom and electron in the uncombined atom. The effect of increased size may be illustrated by comparing water with methyl ether, which may be regarded as water in which the hydrogen atoms are replaced by the larger CH_3 group. The specific inductive capacity of methyl ether and its dissociating power are very much smaller than those of water.

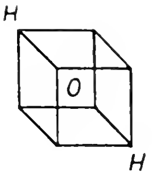
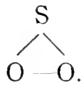


Fig. 16

As another instance of the aid which considerations like these may give in determining the structure of the molecule, we may take the case of SO_2. The determination of its specific inductive capacity shows that it has a finite electrical moment. It is therefore more likely to be represented by one of the unsymmetrical formulas $S=O-O$, $O=S-O$, than by the more symmetrical one  $\overset{\text{S}}{\text{O}-\text{O}}$.

A molecule of a gas with a large electrostatic moment may itself promote combination between two gases, neither of which has molecules with a finite moment. Let us consider the effect of a molecule of this kind on the molecules of a gas near it. The intense electric field round this molecule will drag towards it the molecules round it; it will act as a nucelus round which the molecules of the other gas will condense. The nucleus will thus bring these molecules nearer together than they otherwise would be, and if like chlorine and hydrogen they can combine, the presence of the nucleus will assist combination. It seems possible that part of the action of water vapor in chemical combination may arise in this way, the interacting molecules crowding together so as to get into the strongest part of the electric field round the water molecules and thus getting into positions which are favorable for chemical combination.

In some cases the product of the chemical action will be active molecules with large moment. This will happen in the case of hydrogen and oxygen, or with hydrogen and chlorine, since the molecules of water and hydrochloric acid have a finite electrostatic moment. Here chemical combination promoted by the water vapor produces a fresh supply of active molecules and thus of nuclei which promote the combination. There will evidently be a tendency for mixtures of this type to become explosive. It is the intense electric field round a molecule with a finite electrostatic moment which causes the other molecules to condense round it. If, instead of a molecule with its electrostatic doublet, we had a charged ion, we should have a still more intense electric field and therefore might expect to get still greater condensation and more intense chemical action. The study of the conduction of electricity through gases gives us evidence of the existence of this condensation, as the ions in gases behave more like clusters than single molecules or atoms. It may be asked why is it that while molecules possessing finite electric moments are able to promote so markedly chemical action, yet the speed of these actions is not noticeably greater in ionized than in non-ionized gases, though in the former the ions must produce intense electrical fields? The answer to the question is, that in any ordinary type of ionization the number of charged ions is very small indeed compared with the number of molecules of a foreign constituent of the gas, even when the constituent is present as the merest traces. Take, for example, the case of water vapor, if the partial pressure of the water vapor were only the millionth of an atmosphere there would still be about 2.8×10^{13} molecules of water vapor per cubic centimeter. With such ionizing agents as Rontgen rays, it is exceptionally strong ionization when there are 10^{10} ions per cubic centimeter, so that even with the amount of water vapor mentioned above, which it would be very difficult to avoid, even with the most careful drying, there would be about 2800 times as many molecules as there are ions in an intensely ionized gas. In cases where there are an exceptionally large number of ions present as, for example, in the negative glow in a discharge tube, all kinds of chemical actions seem to go on with great facility.

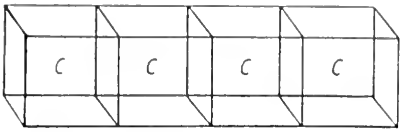


Fig. 17

We shall see later on how these polar molecules are able to bring about dissociation of salts in liquids as well as promote chemical action.

It can be shown[15] that if M is the electrostatic moment of a molecule, *i.e.*, the product of one of the charges into the distance between the charges in an electric doublet which would produce the same electrostatic effect as the polar molecule; then K, the specific inductive capacity of the gas at the absolute temperature T and at a constant density corresponding to that at 760 mm. pressure and 0°C., is given by the equations

$$K = a + \frac{.88M^2 \times 10^{36}}{T} \qquad (26)$$

where a is independent of the temperature. Hence measurement of K at two different temperatures would give us M.

Appiying this formula to the results of Bädeker's experiments, I find that for water

$$M = 2.1 \times 10^{-18} \qquad (27)$$

for ammonia

$$M = 1.5 \times 10^{-18} \qquad (28)$$

It is probable that determinations of K, and thereby of M, at different temperatures for different gases, would give us valuable information as to the lack of symmetry in the molecules of the gas.

Arrangement of Electrons in Octets

We have seen that when a shell of electrons surrounds a positive charge equal to the total charge on the electrons so that the system as a whole is electrically neutral, eight is the maximum number of electrons which can be in stable equilibrium on the shell. If some of the positive charge be taken from the inside of the shell and placed outside in symmetrical positions so as not to destroy the approach to sphericity of the shell of electrons, we can prove that though this transformation will increase the radius of the shell, it will not in general increase the stability, and that eight will still be the maximum number of electrons which can, consistent with stability, be on the shell.

Thus confining our attention to systems such as those formed by collections of atoms where there is no excess of one kind of electricity over the other, eight will be the maximum number of electrons that can be included on a single spherical surface, while, if there are less than eight, the system will not be saturated. It follows from this that any system of electrons and atoms which is stable and saturated must consist of a number of cells of electrons, each cell containing eight electrons and having a charged atom inside. It does not follow that all configurations which can be built up in this way are possible, for though each cell might be stable if all the electrons and positive charges outside it were fixed, yet an aggregate of such cells need not be stable if all the electrons and atoms can move quite freely. Thus we cannot be sure that all distribution of electrons into octets represents a possible compound—as a matter of fact, we know that many do not. Thus to take a system of octets like that shown in Fig. 17, which represents a line of cubes placed face to face, each cube containing a positive charge equal to four. This is an electrically neutral system, and corresponds to a long line of carbon atoms. This system turns out on mathematical investigation to be unstable and therefore a long chain of carbon atoms cannot exist, but would break up into shorter

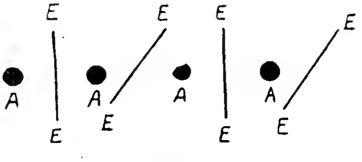


Fig. 18

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[15] *Phil. Mag.*, *27*, p. 763 (1914)

chains, each containing 2, 3 or 4 atoms; this is in accord with chemical experience. On the other hand, long chains of the radicle CH_2 exist in many organic compounds. I have found that the analogous system consisting of a row of doubly charged positive atoms, each of which is at the center of a tetrahedron of electrons as in Fig. 18, is stable. Take, as another example, a long row of cubes placed edge to edge as in Fig. 19, each cube containing a positive charge 6, this would form an electrically neutral system and would correspond to a long chain of oxygen atoms. The mathematical theory, however, shows that this arrangement is unstable and this is confirmed by experience as compounds which contain even very short chains of oxygen atoms are highly explosive.

This division into octets may be regarded as a kind of entrance examination which every candidate for recognition as a formula representing the structure has to pass, and not as being necessarily either the right or even a possible formula. It is a necessary condition which every formula must fulfil, but it is not sufficient to ensure the stability of the compound. It was just the same on the old theory of valency; all kinds of compounds could be imagined which would satisfy the valency condition, but only a small fraction of these have been detected. In fact, chemistry is something more than freehand drawing.

If we wish to find any arrangement of octets which can represent a molecule consisting of specified atoms, we have to solve the following problem. The number of electrons at our disposal is known because we know the atoms of which the molecule consists; we know the number of cells because there is to be one round each of the atoms which in a free state have four or more electrons in the outer layer. Thus we know the number of cells required and the number of electrons at our disposal; we have to see if it is possible to arrange the electrons in octets. If the octets were separate and did not go shares in any electrons, each cell would require eight electrons Whenever we make an octet share an edge with another, we save two electrons; if it shares a triangular face, we save three; if it shares a square face, we save four. We have to try to find contacts between the octets of such a kind that the saving of electrons will equal the difference between eight times the number of cells required and the number of electrons at our disposal. Thus to take an example, suppose we want the arrangement for two oxygen atoms; here two cells are required and there are twelve electrons at our disposal; we have therefore to save four electrons by the contact between the two cells; to do this the octets must have a square face in common, so that the only possible arrangement is that represented in Fig. 20.

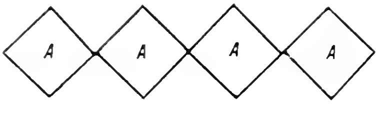


Fig. 19

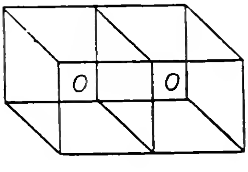


Fig. 20

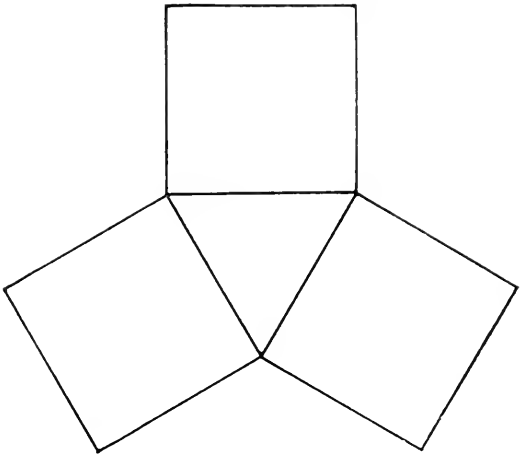
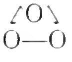


Fig. 21

Suppose, however, we have three oxygen atoms to arrange in a molecule; hence we require three cells and we have eighteen electrons at our disposal; hence we have to save $3\times 8-18=6$ electrons by the contacts. We may do this in two ways: In one represented in Fig. 21, we have three line contacts, at each of which two electrons are saved. In the other, we have that represented in Fig. 22, where we have one line contact, saving two, and a face contact saving four. The first arrangement is represented by  $\overset{/O\backslash}{O—O}$, the second by $O=O-O$; which are two possible formulas for ozone. If both are possible, there must be two kinds of ozone; the first of these being quite symmetrical would represent a molecule without a resultant electric moment, the second we should expect to involve a finite moment. As we can detect the existence of electrostatic moments by experiment on specific inductive capacity, we may hope to find out whether or not there are two kinds of ozone and, if there is only one, which is the formula which represents its constitution.

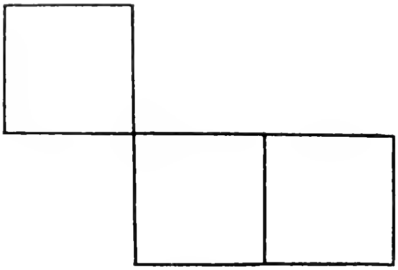


Fig. 22

For CO_2 we require three cells, and we have $4+2\times6=16$ electrons. We have, therefore, to save $3\times8-16=8$ electrons by the contacts; if the atoms are in a line there are only two of these, hence we have to save four at each contact, so that the configuration will be that represented in Fig. 23. This configuration can also be regarded as a quadruply charged carbon atom placed midway between two oxygen atoms surrounded by octets of electrons, each of these systems carrying a charge -2, the molecule being represented by $\underset{-2}{O}=\underset{4}{C}=\underset{-2}{O}$. We may point out that we might have another configuration for the same distribution of electric charges, *viz.*, that represented by Fig. 24; here the oxygen atoms carry the same charge as before, but they present an edge of the octet to the carbon atom instead of the full face. In this case we see that the layer of electrons nearest the carbon atom only contains four electrons, in that represented in Fig. 23 it contains eight. Thus this layer is saturated with the arrangement of Fig. 23, but not with that of Fig. 24. Thus if the electrons in CO_2 were arranged as in Fig. 24, the molecule would not be saturated; it could accommodate, for example, two molecules of water if these were arranged so that the water octet presented an edge to the carbon. While if they were arranged so that each of the water octets presented a point to the carbon atom instead of an edge, it could accommodate four molecules of water. If the oxygen atom also turned a corner to the carbon atom instead of an edge, there would be accommodation for six molecules of water. We thus see that where there are contacts such as those in Fig. 23, which are represented by double bonds between the atoms, we can, by alternating the orientation of the cells, make room for other neutral molecules or radicles. The whole number of systems nearest to the central atom must not, however, exceed eight.

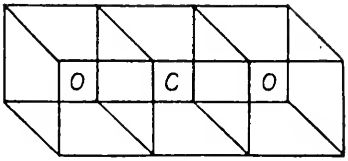


Fig. 23

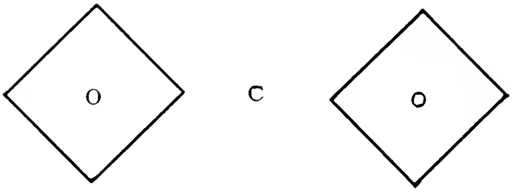


Fig. 24

(To be continued)

Dielectric Strength Ratio Between Alternating and Direct Voltages

By J. L. R. Hayden and W. N. Eddy

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Until the present stage was reached in the general trend toward higher operating voltages and longer distances of transmission, alternating voltage has served well as a universal agent for testing the dielectric strength of the insulation. The great lengths of modern high-voltage cable, however, apparently mark the limit of usefulness of alternating voltage for testing the insulation strength of equipment of high electrostatic capacity. Attention is therefore being directed toward the application of direct voltage for this purpose, made possible by the development of the kenotron tube rectifier. This latter method possesses several decided advantages, but its immediate adoption has been delayed by a lack of knowledge as to what value of direct voltage for test is equivalent to the alternating voltage of operation. The following article, delivered as a paper at the recent Annual Convention of the A. I. E. E., reports an extensive investigation made to determine the dielectric strength ratio, or rather ratios, for various insulating materials.—Editor.

As the operation of electrical apparatus and circuits depends on their insulation, the maintenance and test of insulation is of foremost importance.

Insulation testing, even of direct-current apparatus, is usually done by alternating voltage, since high alternating voltages are easily obtained by the alternating-current transformer.

Two serious disadvantages arose in the use of alternating high potential testing: First, in apparatus of considerable capacitance such as underground cables, the charging current at the high test voltage is excessive, requiring uneconomically large and expensive transformers. Second, in other apparatus, corona and other dielectric losses incident to the abnormally high alternating test voltage (of three and a half and more times the normal operating voltage), may permanently damage the insulation.

With the development of the kenotron vacuum tube as rectifier, high direct voltages became available. As there is no permanent charging current with direct voltage, a kenotron rectifier of a few kilowatts capacity could replace a testing transformer of many hundred kilowatts. In the absence of the intensive corona and the high dielectric losses incident to an alternating field, damage of apparatus by the high testing voltage was less to be feared with direct voltage testing.

At first it was expected that the striking distance with direct voltage would be equal to that of the maximum value of the alternating voltage, and tests made with air as dielectric corroborated this. However, engineers familiar with high-voltage direct-current transmission claimed that apparatus could stand materially higher direct voltages than alternating voltages. When high direct voltages became more available, tests made with them showed that some solid insulation, such as that of cables, stand a higher direct voltage than alternating voltage, and it was hoped then that a constant ratio between the disruptive strength of direct and of alternating voltage could be found, by which the one could be expressed in terms of equality with the other. A series of tests made abroad on cables gave 2.5 as the average ratio between the direct voltage and the (effective or root-mean-square) alternating voltage which has the same disruptive effect.

Further tests made by various engineers here and abroad gave inconsistent results and different ratios between the disruptive effect of direct and alternating voltage, so that now no fixed ratio between direct and alternating voltage can be universally applied.

As the result of several years experimental investigation we have come to the conclusion, and expect to show in the following that:

1. The disruptive effect on insulation of a direct voltage in general is different from that of an alternating voltage of a peak value equal to the direct voltage.

2. The puncture or disruptive effect of the alternating voltage (peak value) may be greater, and sometimes very much greater, than that of the direct voltage of equal value, but it may also be less. That is, the ratio: "Direct voltage divided by the peak value of the alternating voltage which gives the same disruptive effect," which we may call "dielectric-strength ratio," varies from values less than unity, when the direct voltage stress is more severe, to values much above unity, when the alternating voltage stress is more severe.

3. In air, the dielectric-strength ratio is probably unity.

4. In solid insulation, the dielectric-strength ratio depends on the mechanical,

physical, and thermal conditions of the material, and in general, seems to tend towards unity, the more homogeneous the material is.

5. In one and the same material, the dielectric-strength ratio may vary considerably with temperature, thickness, rate of voltage application, etc.

6. In general, it seems that the mechanism of failure of insulation under high alternating voltage stress is materially different in some features from that under high direct voltage stress, and no universal and constant dielectric-strength ratio can therefore be expected, but dependent on the feature which dominates in the failure different values must result.

The dielectric-strength ratio has been defined in previous literature in two ways, either as the ratio: Direct voltage divided by effective or root-mean-square value of alternating voltage (in which case air would have the ratio $\sqrt{2}=1.41$) or otherwise the ratio: Direct voltage divided by the peak value of alternating voltage, which gives to air the convenient ratio 1. We use herein, and recommend for general acceptance, the latter definition, as more rational. It gives the value 1 to air, and in general the values tend toward 1, and it gives the value 1, if the nature of the alternating voltage puncture is the same as that of the direct voltage puncture, since a direct voltage and an alternating voltage with the same peak value should be equivalent.

Although the values given in the following tables are the averages and abstracted from thousands of individual tests, made under the greatest possible precautions, so that the experimental errors are small, they are not so consistent as to draw final conclusions from single recorded values (though these values usually are averages of 10 or 25 tests), and the conclusions are drawn from the general trend of groups of individual values. The reason for variations in results is the inherently erratic nature of disruptive tests. Dielectric tests made with air can be duplicated within two to three per cent, but in liquids like oil erratic variations occur between successive tests made with all precautions, amounting to 20 per cent to 30 per cent and more.[1] In solid insulation, the phenomenon of dielectric disruption apparently is still more complex, and the individual test results therefore are still more erratic, so that acceptable conclusions can be drawn only from the comparison of the averages of very numerous tests.

The results of this investigation seem inevitably to lead to the conclusion that the dielectric rupture under high-voltage stress is a far more complex phenomenon than is usually assumed. Puncture is not due to a mere effect of electrostatic stress, or a mere heating effect, or any specific deterioration effect, etc., but it results from a number of different effects combined in different degrees. While it is somewhat disappointing no universal "dielectric-strength ratio" can be determined, which is applicable to all conditions and all apparatus, we believe that dielectric-strength ratios can be derived for definite classes of insulation under definite operating conditions, and that the determination and study of the dielectric-strength ratio will give us an additional and powerful tool in the study of insulation failure and its causes.

METHODS OF TEST AND APPARATUS

The principal source of high, direct voltage used in the tests was the kenotron. This is a two-element vacuum tube containing a filament cathode supported within a cylindrical plate as anode. The filament is kept incandescent by means of either a transformer or a storage battery. In operation the kenotron acts simply as a unidirectional conductor. passing through only the half waves of one polarity. Figs. 1, 2 and 3 show some of the principal circuits used for kenotron rectification. Fig. 1 is the simplest connection. In this the kenotron is in series with the supply transformer and a condenser storing the rectified voltage. This gives a direct current every second half cycle the vacuum becomes conducting. The principal advantage of such a connection is its simplicity, and if the load is small compared with the condenser capacity, the voltage is quite steady. Fig. 2 shows the bridge type of connection. This has the advantage of passing through both half waves in such a way that they produce the same polarity on the receiving circuit. Fig. 3 shows the full-wave or double-half-wave type which has the principal advantage of requiring an alternating voltage source of only approximately one-third of the direct voltage. The purpose of the condenser is to smooth out the pulsations of the direct voltage. It is readily seen that the half-wave connection, Fig. 1, requires more capacitance than a full-wave connection, either Fig. 2 or Fig. 3. The capacitance required for satisfactory smoothing is dependent on the load. In testing long cables

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[1] "Three Thousand Tests on the Dielectric Strength of Oil," by Hayden and Eddy, presented before Convention of A.I.E.E. at Niagara Falls, June 26–30, 1922.

no capacitance additional to that of the cable is required. But laboratory tests on short lengths of cable or other test pieces of low electrostatic capacity necessitate the use of the condensers shown. On account of the small direct current conducted by any type of insulation the voltage fluctuation of such a rectifier can be reduced below 2 per cent without the necessary condensers becoming large.

Both the alternating and the direct-voltage data were taken on the same transformer. The direct voltage was obtained by means of the full-wave kenotron connection, Fig. 3, using sufficient capacitance in parallel with the sample to reduce the ripples in the voltage wave to less than 2 per cent under the conditions of tests. In taking all spark voltage values special attention was given to the rate of increasing the voltage, keeping this rate as nearly the same as possible at the value noted in the data.

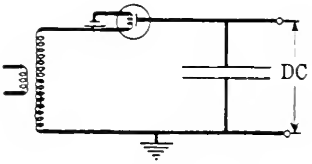


Fig. 1. Simple Connection of Kenotron Rectifier

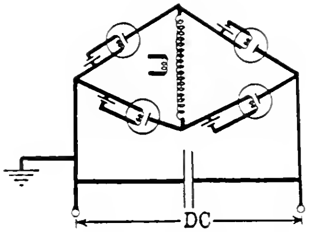


Fig. 2. Bridge Type of Kenotron Rectifier Connection

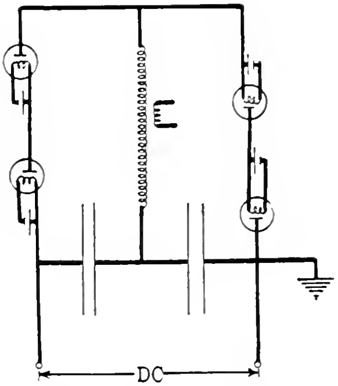


Fig. 3. Full-wave Kenotron Rectifier Connection Requiring an Alternating Voltage of but One-third the Direct Voltage

The various types of insulation were tested in various forms and shapes and with various electrodes but care was always taken to have no sharp corners or edges on the electrodes. All voltage readings were taken on the low side of the supply transformer and the high-tension voltage, whether alternating or direct, was obtained from a calibration curve which had been made against a sphere gap in parallel with the sample or an equivalent load. All direct-voltage data below 3000 volts were taken on a special direct-current generator with field control, the voltage being read by an indicating voltmeter in series with multiplying resistance. Whenever possible both alternating and direct voltage punctures were taken on the same sample of insulation. For instance, if the sheet of insulation under test was large enough for 10 puncture tests, 5 would be taken on alternating and 5 on direct voltage. At no time were more than 5 punctures taken on alternating voltage without then taking an equal number on direct voltage or vice versa so as to give the closest possible comparison Each value given in the tabulations is usually the average of 10 to 25 tests. Practically all of the tests were repeated at different times by different operators and under different experimental conditions.

RESULTS OF TESTS

A. Oil, Petrolatum and Cable Paper

A series of tests were made on the materials entering the insulation of high-potential cables, such as petrolatum and cable paper, and the results of these tests are given in Table I. In the same table are also given the results with transil oil No. 6, as of similar character to petrolatum but far more fluid. Oil and petrolatum were tested between 2.54 cm. spheres, but cable paper was tested between 5 cm. plates. The alternating voltage values are the maximum of the voltage wave.

The table gives the tested materials: Transil oil No. 6 alone, petrolatum alone, manila paper of 0.2 mm. thickness in air dry condition alone, and the same paper impregnated with petrolatum. The table also gives the length of the gap between the spheres for oil and petrolatum, and the number of layers of cable paper used. Then it gives the approximate rate of voltage increase in percent-per-second of the puncture voltage. Then follow the values of direct voltage in kilovolts, and of alternating voltage, peak values for the four temperatures 25, 50, 75, and 100 deg. C., and finally in the four last columns, the values of the "dielectric-strength ratio" derived by dividing the direct-voltage by the alternating voltage. As seen, values are given for three rates of increase in terms of the puncture voltage as follows: 20, 5, and 0.1 per cent rise of this voltage per second. Each of the numerical values given in Table I is the average of a minimum of 10 to 25 observations, but in many cases as many as a hundred repetitions were made.

a. Oil. The table shows incidentally that the dielectric strength of oil, with direct voltage as well as with alternating voltage, decreases somewhat with increasing temperature, but not to any great extent.

As would be expected from the erratic behavior of oil, the values of the dielectric-strength ratio of the oil, given in the last four columns, differ from each other more than any possible error of observation. However, in general the data show fairly conclusively a dielectric-strength ratio somewhat below unity, specifically a general average of $R=0.923$. In other words, this ratio of 92 per cent indicates that *oil has a greater dielectric strength under alternating than under direct voltage*, by about 8 per cent.

TABLE I

OIL, PETROLATUM AND CABLE PAPER

Material	Electrodes	Length of gap mm.	Rate of voltage rise per cent per sec.	Direct voltage kv.				Alternating voltage kv.				Dielectric-strength ratio			
				25 deg.	50 oeg.	75 deg.	100 deg.	25 deg.	50 deg.	75 deg.	100 deg.	25 deg.	50 deg.	75 deg.	100 deg.
Transil oil No. 6	2.54 cm. spheres	2	5	30.5	28.8	27.6	19.9	32.9	27.2	27.0	25.3	0.927	1.059	1.022	(0.785)
		4	5	45.8	37.5	36.2	34.0	53.0	45.0	40.4	37.7	0.864	0.833	0.896	0.902
		2	2	20.7		20.5		25.4		19.5		0.815		1.051	
		4	2	36.7		37.0		49.0		42.9		(.755)		0.862	
Petrolatum	2.54 cm. spheres	2	5	15.1	15.6	17.8	15.1	15.9	22.7	18.4	15.9	0.950	(.687)	0.967	0.950
		4	5	27.6		34.8	28.2	28.9		35.9	29.6	0.955		0.969	0.953
		No. of layers													
Cable Paper 0.2 mm. thick air	5 cm. plates	4	20	4.3	3.4	3.6	3.2	2.4	2.5	2.3	2.2	1.790	1.360	1.565	1.445
		8	20	9.0	8.4	7.7	7.0	7.0	6.6	5.5	5.5	1.286	1.273	1.400	1.273
		16	20	17.3	12.8	12.7	13.1	16.1	12.0	11.6	9.7	1.075	1.067	1.095	(1.340)
		32	20	33.1	26.6	24.5	26.5	30.5	28.0	28.0	28.0	1.085	0.950	0.875	0.946
		4	5	5.4	4.84	5.47	4.4	4.19	4.15	4.25	4.33	1.290	1.176	1.287	1.016
		8	5	7.6	7.5	8.7	9.0	7.39	7.32	8.97	8.72	1.028	1.025	0.969	1.032
		16	5	14.0	13.0	15.2	15.2	12.8	12.9	13.6	15.3	1.094	1.078	1.117	0.993
		32	5	22.5	13.1	15.3	20.3	18.7	13.2	15.6	20.7	1.203	0.992	0.981	0.981
		4	0.1	5.3	4.7	4.5	4.0	4.5	4.1	4.2	4.0	1.178	1.147	1.072	1.000
		8	0.1	9.2	9.4	7.8	8.3	8.8	7.8	7.8	7.8	1.045	1.205	1.000	1.064
		16	0.1	15.5	13.6	12.7	13.5	16.3	14.7	14.0	14.3	0.951	0.925	0.907	0.944
		32	0.1	27.5	25.5	24.3	22.5	31.5	29.7	28.9	28.3	0.873	0.858	0.841	0.774
Cable Paper 0.2 mm. thick. impregnated with petrolatum	5 cm. plates	1	20	7.4				3.0				2.470			
		2	20	18.3	19.0	15.0	15.1	6.6	10.6	8.7	7.8	2.775	1.793	1.725	1.940
		4	20	31.0	41.5	39.3	29.5	15.8	25.3	24.6	20.3	1.960	1.635	1.605	1.453
		1	5	9.4	8.0	6.7	7.5	7.0	6.5	5.6	6.5	1.343	1.232	1.197	1.154
		2	5	36.0	22.8	17.7	22.4	18.2	15.9	14.3	13.6	1.980	1.435	1.238	1.650
		1	0.1	5.0				3.2				1.565			
		2	0.1	16.2	14.4	13.8	14.7	7.0	7.3	8.0	8.5	2.314	1.975	1.725	1.735
		4	0.1	29.5	36.5	34.0	25.7	15.5	20.3	21.7	20.5	1.900	1.795	1.570	1.253

A Comparison of Ratios at Different Temperatures. The combined averages of all the ratios at 25 and 50 deg. C. is $R=0.900$; but the combined averages of all the ratios at 75 and 100 deg. C. is $R=0.947$. This change shows that the dielectric-strength ratio increases with increasing temperature or, as we may say, becomes more normal at higher temperatures by approaching closer to the value of unity.

Ratios at Different Gap-Lengths. The average ratio for the short oil gap is $R=0.975$; the average ratio for the long gap is 0.871. This difference shows conclusively that the dielectric strength ratio of oil seems to become more abnormal, that is, differs more from unity, with increasing length of oil gap. This conclusion, however, requires further corroboration.

Ratios as Affected by Rate of Increase of Voltage. For the slower rate of increase of voltage, 2 per cent per second, the ratio averages $R=0.909$; for the faster rate of 5 per cent per second it averages $R=0.929$. The conclusions drawn from this small change of 2 per cent also require further corroboration.

b. Petrolatum. Petrolatum is stated to be an amorphous hydrocarbon, essentially of the paraffin series. At room temperature it has the consistency of vaseline, and as a closely related hydrocarbon it shows the same general characteristics as transil oil.

As seen from Table I, the dielectric strength of petrolatum, under direct or alternating voltage, does not appreciably change with the temperature, between 25 and 100 deg. C., nor is there appreciable change in the dielectric-strength ratio.

The averages of the dielectric-strength ratio, taken from the table:

At:	25 deg.	75 deg.	100 deg. C.
$R =$	0.952	0.968	0.952

Thus the ratio is essentially constant.

Again as regards variation in gap-length:

At: 2mm. 4mm. length of gap between spheres:

$R =$ 0.956 0.959 respectively, which is also essentially constant over this small range of gap.

The average of all values of dielectric-strength ratio for petrolatum is: $R = 0.957$. Therefrom it is evident petrolatum shares with oil the characteristic that its dielectric strength is less for direct voltage than for alternating voltage, but the difference is not so great.

If the abnormal behavior of oil were due to differences in the mechanical motion produced in the ingredients of its unhomogeneous structure by the continuous dielectric field, the resultant concentration of the weaker ingredients might account for its lesser strength under the continuous direct voltage than under the alternating voltage stress, and the far more viscous petrolatum would show still less the effect of any movement and concentration—as is, in fact, the case.

c. Dry Unimpregnated Cable Paper. Incidentally tests with direct and alternating voltage show no definite difference in effect on the dielectric strength of cable paper, within the range of temperature and rate of voltage rise used in the tests. But there is a very pronounced effect on the dielectric-strength ratio, as seen from the three sets of values in the last four columns of the table which tabulate 48 results, each the average of a number of tests. Ratios are given for the three general factors; viz., for temperatures from 25 to 100 deg. C., for thickness from 4 to 32 layers of 0.2 mm. paper, and for rates of voltage rise from 0.1 of 1 per cent per second to 20 per cent per second. Although individual values may fall somewhat out of line, there is a very pronounced grouping of the results. The highest values of dielectric-strength ratio occur at the lowest temperature, at the lowest thickness and at the highest rate of voltage rise (shown in the table at the top left-hand corner). On the contrary, the lowest values of the ratio occur at the highest temperature, the thickest insulation, and the slowest rate of voltage rise (shown at the bottom right-hand corner). It is interesting to note that with dry paper, unlike oil, the ratio extends to both sides of unity. There are some values materially above 1, and there are also values below 1.

To get the general trend of variation of the ratio, with each separate feature, we average all the values for the same temperature, or for the same thickness, or for the same rate of voltage rise, and thus get the effect of one variable, segregated from the effect of the others. This grouping of data gives the following results:

Temperature, Thickness, and Rate Data for Dry Unimpregnated Cable Paper.

Temperature:	25 deg.	50 deg.	75 deg.	100 deg.
Average ratio: $R =$	1.158	1.088	1.092	1.057

There is a consistent decrease of ratio with increasing temperature.

Thickness:	4	8	16	32 layers
Average ratio: $R =$	1.277	1.133	1.027	0.947

There is a consistent decrease of ratio with increasing thickness, from values considerably above 1 to values below 1.

Rate of voltage rise: per sec.	20 per cent	5 per cent	0.1 of 1 per cent
Average ratio: R =	1.231	1.079	0.987

There is a consistent decrease of ratio with decreasing rate of voltage application, down to values below unity.

The total average of all the values of the dielectric-strength ratio of cable paper is slightly above unity: $R = 1.100$. In other words, dry cable paper shows a slightly lesser dielectric strength for alternating than for direct voltage. Conversely stated, unimpregnated paper requires, on an average, a 10 per cent higher direct voltage than the peak alternating voltage to puncture the same thickness of paper under otherwise identical conditions.

Since a laminated structure, consisting of a number of layers of unimpregnated cable paper, thus shows also a small deviation from the normal dielectric-strength ratio but opposite to that of either oil or petrolatum, it is of interest to consider the combination of both; i.e., cable paper impregnated with the insulating hydrocarbon.

d. Cable Paper Impregnated with Petrolatum. If untreated cable paper (with a dielectric-strength ratio slightly above unity; viz., 1.100) is impregnated with petrolatum (which alone has a ratio slightly below unity, viz., 0.957) we might expect as a result of the combination of the two a ratio close to unity. On the contrary, the tests of impregnated paper show consistently very high ratios, much higher indeed than dry paper, and give an average ratio $R = 1.773$.

This result is very startling and its significance on insulation strength and failure is still far from being understood. The phenomenon of extra high ratio has, however, been checked and corroborated with data on several other materials of similar character.

Significant also is another factor, the enormous increase of dielectric strength due simply to impregnation of the paper.

To get the general trend of the variation of the dielectric-strength ratio with the three controllable variables, viz., temperature, thickness, and rate of voltage application, the tabulated data are again grouped for the purpose of comparison.

Temperature, Thickness, and Rate Data for Cable Paper Impregnated with Petrolatum.

Temperature:	25 deg.	50 deg.	75 deg.	100 deg.
Average ratio: $R =$	2.038	1.644	1.510	1.531

Thus the ratio consistently decreases with increasing temperature.

Thickness·	2	4 layers
Average ratio: $R =$	1.857	1.646

Thus the ratio decreases with increasing thickness.

Rate of voltage rise: per sec.	20 per cent	5 per cent	0.1 of 1 per cent
Average ratio: $R =$	1.861	1.576	1.783

Thus the general trend is apparently that the ratio decreases with increasing slowness of voltage application, although the slowest rate shows a partial recovery.

This last group of data illustrates the difficulty of the investigation of the action of solid insulating material and emphasizes the complexity and limited knowledge of the phenomena occurring in insulating materials under electric stress. The values averaged in the middle figure (1.576 at 5 per cent rate) were taken some weeks before the other two sets of tests, and while apparently the same materials were used and treated in the same manner and the general trend of variation is the same, a considerable difference occurs in the numerical values.

It is interesting to note that the ratio of direct voltage to peak alternating voltage of petrolatum-impregnated cable paper, $R = 1.773$, in the comparison of direct voltage with the root-mean-square value results in the ratio $\sqrt{2}\ (R = 1.773) = 2.501$. This value is the same as has been proposed as the results of extensive tests made abroad on cables.

B. Mica and Glass

Table II gives data on some inorganic insulation, such as mica and its compositions, and also glass. The table gives the name of the material, the data on sizes of electrodes, and either the gap length or number of layers; there are also the voltages of the tests using either direct or alternating voltage, and their ratio; i.e., the dielectric-strength ratio of these materials. Here, as in the preceding table, each numerical value is the average of a number of tests, usually 10 or 25. For some of the materials, such as clear and pasted mica, glass, etc., the dielectric-strength is given in kilovolts per millimeter, so as to

TABLE II

MICA, GLASS AND PARAFFIN

Material	Electrodes	Gap cm. length	No. of layers	Direct	Alternating	Dielec. str'gth ratio
				kv. per mm.		
Clear Mica, 0.12 to 0.18 mm. thick...				100.5	98.0	1.025
Pasted Mica, 0.32 to 0.35 mm. thick...				60.5 kv.	48.6 kv.	1.245
Mica Tape on Brass Tube............			2	14.05	8.55	1.64
			4	34.9	21.9	1.59
			8	70.7	45.1	1.57
Mica Tape without sticking compound			2	12.7	7.3	1.74
			4	21.5	12.7	1.69
			8	66.4	27.5	(2.42)
Mica Tape with sticking compound			2	24.5	9.6	2.55
			4	48.1	20.2	2.38
	diam.			kv. per mm.		
Glass Tubing 0.7 to 0.85 mm. thick...	2.54 cm.			68.0	46.3	1.469
Powdered Glass....	2.54 cm. spheres	1.90		kv. 37	kv. 44.5	0.832
		2.54		51.9	53.8	0.965
Powdered Glass made into paste with No. 6 transil oil..	2.54 cm. spheres	0.63		56.8	61.6	0.922
		0.95		71.2	73.8	0.965
				kv. per mm		
Cast Paraffin 0.9 to 2.2 mm,. thick ...				17.4	16.8	1.036

compare the averages of the different tests made with slightly different thicknesses of material.

The Dielectric-Strength Ratio of Mica in Several Forms. Clear mica gives a dielectric-strength ratio very little above unity, that is, in pure mica the dielectric-strength is practically the same for alternating as for direct voltage. Possibly this low value of ratio indicates very low dielectric losses. Built-up or "pasted" mica, however, already shows a materially lesser strength for alternating than for direct voltage, a ratio of 1.245. Mica tape shows still much higher ratios, and mica tape put together with some organic sticker shows very high values. A comparison is made in the following averages:

Clear Mica	a ratio of 1.025
Pasted Mica	a ratio of 1.245
Mica Tape	a ratio of 1.646
Mica Tape held by a sticker	a ratio of 2.46

Therefore the combination of two different materials in a laminated structure, here as in the preceding Section A for impregnated paper, seems to raise the ratio. The ratio increases with the increase in the difference between the materials.

Apparently there is also a slight decrease of ratio with increasing thickness of the insulation, such as observed in the preceding studies.

The Dielectric-Strength Ratio of Glass and Paraffin. Glass was tested, in the form of thin walled glass tubes, with mercury as inner electrode and tinfoil as outer electrode. Somewhat against expectation, glass, as the average of a number of tests, gave a high ratio, viz., 1.469. That it to say, glass is dielectrically much stronger against direct than against alternating voltage. Whether this high ratio indicates a lack of homogeneity of the structure of the glass—as a colloidal solution—we cannot yet judge.

The glass of the tubes was powdered and the powdered glass in air was tested between 2.54 cm. spheres. Next, the powdered glass was mixed with No. 6 transil oil to form a paste, and this paste tested between 2.54 cm. spheres. Both the glass powder with the spaces between the particles filled with air, and that with the spaces filled with oil, show a dielectric-strength ratio slightly below unity (total average 0.921). That is, glass in solid form has a much greater dielectric strength for direct than for alternating voltage; as powder, however, its dielectric strength is less for direct than for alternating voltage. The explanation of this difference is still unknown.

In the same table have been added the averages of a number of tests made on thin cast disks of paraffin. They show a ratio close to unity, viz., 1.036. This result seems reasonable.

TABLE III

VARNISHED CAMBRIC AND PARAFFINED PAPER

Materials	Electrodes	No. of layers	Rate of voltage rise per cent per sec.	Direct voltage kv.				Alternating voltage kv.				Dielectric-strength ratio			
				25 deg.	50 deg.	75. deg	100 deg.	25 deg.	50 deg.	75 deg.	100 deg.	25 deg.	50 deg.	75 deg.	100 deg.
Black varnished cambric 0.3 mm. (asphaltum base)	5 cm. plates	1	1	21.8	18.1	16.0	14.5	17.4	15.9	15.6	14.7	1.253	1.138	1.026	1.014
		2	5	40.2				29.4				1.367			
Yellow varnished cam. 0.2 mm. (linseed oil base)		1	5	11.9	14.2	13.2	12.0	11.1	12.6	11.5	11.7	1.072	1.127	1.148	1.026
		2	5	19.3	23.8	21.0	19.2	17.3	22.4	22.2	19.4	1.116	1.062	1.054	0.900
		4	5	31.3	43.1	39.4	30.8	26.5	41.1	32.4	28.6	1.177	1.049	1.215	1.077
		1	5	19.4	20.1	14.0	9.5	14.4	15.0	9.2	10.2	1.347	1.340	1.525	0.932
		2	5	35.7	36.0	27.6	21.8	27.6	27.1	22.7	22.0	1.293	1.329	1.216	0.990
		4	5			43.5				42.2				1.031	
		1	2	21.2	18.0	11.5		14.4	13.9	9.8		1.472	1.295	1.173	
		2	2	38.8	31.7	22.5		24.2	23.5	22.4		1.600	1.350	1.005	
Cable Paper 0.2 mm., impregnated with paraffin		1	5	20.1				14.0				1.437			
		2	5	32.3				22.4				1.442			

C. Varnished Cambric and Paraffined Paper

Table III gives data on two kinds of insulating cloth—black and yellow varnished cambric, and cable paper impregnated with paraffin. Cable paper inpregnated with paraffin gives in general the same characteristic as cable paper impregnated with petrolatum, as might be expected, i.e., a high value of the ratio.

The data on both kinds of varnished cloth seem to show a decrease of dielectric strength with increasing temperature, and also a decrease of the dielectric-strength ratio with increasing temperature and possibly also with increasing thickness. Thus, grouping the average values as was done in previous cases, the results are as follows:

Temperature and Thickness Data for Yellow Varnished Cloth.

Temperature:	25 deg.	50 deg.	75 deg.	100 deg. C.
Average Ratio: $R =$	1.297	1.222	1.171	1.003
Thickness:	1	2	3 layers	
Average Ratio: $R =$	1.231	1.193	1.080	

The total average is $R = 1.186$.

The similarity of the change of the ratio in varnished cloth, with that in impregnated paper, raises the question whether it is not a general characteristic of compound laminated structures to have a high dielectric-strength ratio at low temperatures, low thicknesses, and high rates of voltage rise, and conversely to have this ratio decrease with increasing temperature, increasing thickness, and increasing slowness of voltage application.

Periodic Inspection, Cleaning, and Testing of Alternating-current Generators

Offhand, it would appear as if those in charge of electrical machinery would realize that regular and efficient inspection and cleaning are essential to the satisfactory performance of the equipment. A recent survey of the field, however, revealed an astonishing lack of appreciation of the importance of this branch of maintenance work and also a wide divergence in its mode of conduct. Because the lack of proper care in operation almost always results in expensive repairs, the precautionary measures and other instructive information in this article should be found to be of value.—EDITOR.

There is a great divergence of practice among operating companies in regard to the periodic inspection, cleaning, and testing of alternating-current generating equipment. The following suggestions are made in the hope that they may serve as a basis for more uniform practice in these important items of maintenance.

Inspecting

One of the fundamentals of successful operation of electrical generating equipment is frequent, thorough, and systematic inspection. Such inspection will often give warning of approaching trouble and thus allow the operator to take precautions that will prevent a serious breakdown and consequent damage to the generating equipment.

It is the practice of some operating companies to inspect all generators each day. This is an excellent precaution and highly recommended. It is understood that operating conditions may not permit such frequent inspections, but nothing should interfere with the thorough inspection of each machine as soon as it is shut down. No definite rule can be laid down, but the principle should be recognized that frequent inspections are vital to the proper maintenance of all generating equipment. All inspections should be thorough. While a casual inspection is perhaps better than none, the value of an inspection depends on the care used in making it.

The inspection should always include the armature windings and field coils of the main generator in so far as they are visible and accessible, the armature, field coils, and commutator of the exciter (if there is one), the collector rings, all brushes and brush-holders, bolts, nuts, dowels and all other mechanical and electrical parts and fittings. Lubricating oils are injurious to insulations and also to concrete foundations, and all bearings and oiling systems should be examined for oil throwing and leaks. In the case of steam turbines, the turbine itself so far as possible, and the valves, valve gear, governor, throttle, and other parts should be included.

Haphazard inspection by anyone in the plant cannot be considered systematic. A definite routine of inspection should be standardized and every part should be taken up in order. Station superintendents should compile a list of all parts subject to inspection, and insist that inspectors use this list, checking off each item as it is examined. The inspector should be thoroughly familiar with what to look for and should be drilled in his work so as to guard as much as possible against the omission of any part.

Cleaning

All generating equipment will accumulate dust and dirt in the course of time; even the use of air washers does not altogether eliminate this trouble. This dust and dirt lodges in the air ducts and on the ends of the windings, interfering with the free circulation of the cooling air and the radiation of heat from the windings, and at the same time increases the fire hazard.

The life of generating equipment may be prolonged by frequently blowing out the dirt with compressed air. In large turbine-generators this is a difficult matter, if indeed it is possible, owing to the design of the generator frame and end bells. On other types of machines, however, such as water-wheel generators, the air ducts and windings are more exposed and are accessible to this form of cleaning. If possible, the compressed air should be used every day but, before doing so, care should be taken to make sure that the air stream is free from water. If it is not convenient to shut down a machine, such blowing out as is possible can be done while the machine is running.

All generating equipment should be thoroughly cleaned once a year or more, if operating conditions are such as to require it. Special attention must be given to machines operating in localities where the air is contaminated with dust, lint, coal dirt, cement dust, and the like. Under such conditions, arrangements should be made for a thorough cleaning at frequent intervals. To insure that this periodic cleaning be thorough, the end bell covers and similar parts should be taken off to expose fully the end turns of the windings and the air ducts. The revolving field should also be removed, so that it can be cleaned and examined, and at the same time permit the cleaning and inspection of the inside of the armature.

Loose dirt can be removed by wiping, brushing, the use of compressed air, bellows, or by some form of vacuum cleaner. Should dirt and dust be lodged with oil, it may be removed with gasoline, benzine, or carbon tetrachloride. In using any of these, limit the quantity to that required for the purpose in hand. Too much liquid is liable to flush the dirt into inaccessible places. After using any of these solvents, all the surfaces to which they have been applied should be carefully and thoroughly dried. Care should be exercised when using gasoline or benzine because of their inflammable properties. Special attention should be given to ventilation, not only because of the danger of explosion but also because the fumes of all three are injurious to the workman, particularly if working in a pit where fumes are likely to collect. In using gasoline, care should be taken to obtain a good quality, since a poor quality is liable to leave a coating of oil or other substance on the windings and in inaccessible places, which will cause the rapid accumulation of dirt and dust. Test all gasoline by allowing a small quantity to evaporate in a porcelain dish. If the quality is good, no residue or odor will remain. After cleaning and before re-assembling the parts, spray the exposed windings with a high grade of air-drying insulating varnish. While the machine is disassembled, all electrical parts and connections and all mechanical parts should be carefully examined and such tests applied as may be considered advisable.

Testing

No definite rules can be established for testing generating equipment which has been in operation for any length of time. The permissible test depends particularly on the age of the machine, on the character of the service to which it has been subjected, and on the type of insulation used on the windings. All insulation deteriorates with age and use, particularly where organic material forms a large part of the total. An old machine or one that has been subjected to severe operating conditions will not stand, nor should it be subjected to, the same test that might be applied with safety to a comparatively new machine.

There comes a time in the life of all equipment when the deterioration reaches the point of breakdown and, when this occurs, expensive repairs are usually the result. For the purpose of enabling operators to determine the approach of this time, various tests have been devised and are now in use.

The ordinary so-called megger is frequently used to measure the resistance of insulation. The results obtained are difficult to interpret owing to the many varying factors that must be considered and for which due allowance must be made in the results. The voltage of the megger is usually low compared to that of the machine being measured and this also tends to limit the accuracy of the measurement. Despite these objections, however, the megger is very widely used among operators and some claims are made of great benefits from the use of this device.

The combination of high voltage (at least as high as that of the machine in test) and direct current gives the most effective results. This combination is best obtained by the kenotron measuring set. With this set, the true leakage current is measured and the readings are not influenced by the detrimental effects of the alternating-current voltage supplied by the small generators of the megger and similar instruments. If insulation tests are to be relied upon to give warning of coming trouble, the kenotron is recommended as giving the most accurate and reliable results.

There frequently arises the question of applying a high potential test, or what might be called a generated overvoltage test (running the generator at overvoltage by increasing the excitation or speed, or both) to determine the condition of the insulation. The answer must take into account the various insulating materials used, the age of the machine, and the operating conditions, particularly regarding overloading and periodic examination and cleaning. General approval in the abstract, at least, will be accorded the statement that "the insulation of all generating equipment should be maintained in such condition as to withstand safely the application of a 50 per cent overvoltage test." Whether such conditions can be maintained and whether such a test is desirable are questions difficult to answer. Not until operating conditions are standardized and operators' ideas on this subject correlated, can a satisfactory answer be obtained. The following tests have been used successfully under various operating conditions and will no doubt be of interest.

After the generators have been carefully examined and thoroughly cleaned, they have been run on open circuit with sufficient excitation to raise the terminal voltage about 25 per cent above normal for five minutes. After that test, the voltage has been reduced to normal and the several terminals grounded in succession. In making this test, arrangements must be made to break the field current instantly in case of failure.

This test is more searching than the application of an equivalent alternating-current potential from a testing transformer. The latter or so-called high potential test is usually made between the windings and ground, whereas the generated voltage test described is in reality a test from turn to turn, from coil to coil, and from phase to phase.

A test frequently used on the windings of revolving fields is to subject them to two or three times normal exciting voltage, applied between one terminal and the shaft. The test should be applied while the field is running at normal speed and may be made with either direct or alternating current as may be most convenient.

High potential tests using a testing transformer vary widely among different operators. Tests are required on armatures ranging from 10 to 60 per cent over normal and are applied for periods of time varying from one to 30 minutes. On revolving fields, voltages up to six times normal are applied for widely varying periods.

When attempting either the generated voltage or the familiar high potential test, the windings should be exposed as much as possible so that any failure can be seen immediately and the test voltage instantly removed.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Arc Welding
Applications of Arc Welding to Ship Construction. Ewertz, E. H.
Mar. Engng., July, 1923; v. 28, pp. 420-424, 440.
(A review of the subject in general, prepared under the auspices of the American Bureau of Welding. Serial.)

Car Lighting
Principles of Car Lighting by Electricity. Stuart, Chas. W. T.
Rwy. Elec. Engr., July, 1923; v. 14, pp. 199-205.
("A comprehensive description of the parts and operation of the USL Type C equipment and the P. R. R. type.")

Carrier-Current Communication
Emergency Communication by Guided Radio Telephone. D'Alton, F. K.
Bul. of Hyd. Pr. Comm. of Ont., June, 1923; v. 10, pp. 183-192.

Cars, Electric
Single-phase, Type Ce 4-6 Motor Cars of the Swiss Federal Railways. (In German.)
Schweiz. Bau., July 7, 1923; v. 82, pp. 13-16.
(Illustrated description. Serial.)

Condensers, Static
Use of Static Condensers for the Improvement of Power-factor. Meyer, G. W. (In German.)
Trua, July 1, 1923; v. 4, pp. 243-247.
(Advantages, mechanical and electrical design, etc.)

Corrosion
Rapid Corrosion of Condenser Tubes. Bengough, Guy D., and May, R.
Engr., July 6, 1923; v. 136, pp. 7-10.

Electric Cables
Current Loading of Cables. Melsom, S. W.
Beama, July, 1923; v. 13, pp. 30-36.
(Author is connected with the National Physical Laboratory in England. Serial.)

Electric Current Rectifiers
Mercury Vapor Rectifiers for Street Railway Systems. Odermatt, A. (In French.)
Ind. des Tram., June, 1923; v. 17, pp. 197-216.
(Extensive, illustrated report presented before the Congrès International de Tramways, at Brussels, October, 1922.)

Electric Distribution
Sources of Power for Three-wire Direct-current Systems. Hancock, M. S.
Elec. Jour., July, 1923; v. 20, pp. 267-269.
(Discusses three ways of supplying power to a three-wire system.)

Electric Drive—Paper Mills
Electric Drive for Sectional Paper Machines. Cordes, O. C.
Elec. Jour., July, 1923; v. 20 pp. 236-241.

Electric Drive—Power Plant Auxiliaries
Alternating-current Versus Direct-current Motors for Stoker Drive. Douglas, W. E., and Bates, Harry H.
Power, July 3, 1923; v. 58, pp. 8-9.

Electric Heating, Industrial
Application of Electricity for Heating Purposes. Zeulmann, Edgar. (In German.)
Zeit. des Ver. Deut. Ing., June 23, 1923; v. 67, pp. 617-622.
(Illustrated review of industrial electric heating processes.)

Electric Locomotives
Service Records of Electric Locomotives and Motor Cars.
Elec. Trac., July, 1923; v. 19, pp. 347-349.
(A collection of operating experiences on seven electrified lines.)

Electric Measurements
Measurement of a Single-phase Load at a Low Power-factor. Dovjikov, A.
Elec. Jour., July, 1923; v. 20, pp. 258-261.

Electric Meters
New Development in Alternating-current Instruments. MacGahan, Paul.
Elec. Jour., July, 1923; v. 20, pp. 252-257.
(Discusses the design of a new and complete line of instruments operating on the dynamometer principle.)

Electric Motors, Induction
Starting Torque and Current of Squirrel-cage Induction Motors. Wall, T. F.
Elec. Rev. (Lond.), July 13, 1923; v. 93, pp. 44-46.

Electric Motors, Railroad
Selecting a Railway Motor for a Given Cycle of Duty. Gordon, W. G.
Elec. Rwy. Jour., July 14, 1923; v. 62, pp. 62-64.
(Abstract of paper before the Canadian Electric Railway Association.)

Electric Motors, Synchronous
Autosynchronous Motors. Lindstrom, A.
Elec'n, July 6, 1923; v. 91, pp. 4-5.
(Serial.)

Electric Transformers

Care and Operation of Power Transformers from the Standpoint of Those in Charge of Their Installation and Maintenance.
Ind. Engr., July, 1923; v. 81, pp. 348-355.
(Recommendations of Electric Power Club.)

Ratio Regulating Taps of Transformers. Bunet, P. (In French.)
Revue Gén. de l'Elec., July 7, 1923; v. 14, pp. 17-27.
(Discusses mechanical and electrical difficulties occasioned by transformer taps.)

Electric Transmission Lines

Spacing and Wire Stresses of Catenary Supporting Structures. McGee, P. A.
Elec. Jour., July, 1923; v. 20, pp. 248-252.
(With reference to wind load effect.)

Underground Transmission at 44 Kv. Dennis, R. E., and Searing, H. R.
Elec. Wld., July 14, 1923; v. 82, pp. 65-69.

Electrical Machinery—Parallel Operation

Parallel Operation of Direct-current Generators. Hancock, Scott.
Power Pl. Engng., July 1, 1923; v. 27, pp. 684-687.

Electrical Machinery—Temperature

Cooling of Turbo-generators. Luke, George E.
Elec. Wld., July 14, 1923; v. 82, pp. 70-72.

Electricity—Applications—Domestic

Domestic Refrigerating Machine.
Ice & Refrig., July, 1923; v. 65, pp. 1-7.
(Discusses relative operating costs of mechanical and ice refrigeration. Gives list of manufacturers with illustrations and descriptions of their products. Serial.)

Feed Water Heaters

Effect of Feedwater Heating on Plant Economy. Bell, G. G.
Mech. Engng., July, 1923; v. 45, pp. 417-420, 429.

Frequency Changers

Reduction of the Frequency of Alternating Currents by Means of Lamps with Cathode Emission. Blusson. (In French.)
Revue Gén. de l'Elec., July 7, 1923; v. 14, pp. 7-16.
(Summary of theories of a frequency changer involving mercury vapor arc principles. Serial.)

Heat Transmission

Laws of Heat Transfer.
Engng., July 6, 1923; v. 116, pp. 1-3.
(Serial.)

Hydro-electric Development

Hydro-electric Developments in Ontario. Gaby, F. G.
Mech. Engng., July, 1923; v. 45, pp. 410-416.
(Present and projected developments; also data on the Queenston-Chippawa plant.)

Inductive Interference

Electric Traction Interference with Telegraph Circuits. Thorrowgood, W. J.
Rwy. Gaz., July 6, 1923; v. 39, pp. 19-20.
(Short account of a system used on the Italian State Railways for preventing inductive interference.)

Insulation—Testing

Dielectric Strength Ratio Between Alternating and Direct Voltages. Hayden, J. L. R., and Eddy, W. N.
A.I.E.E. Jour., July, 1923; v. 42, pp. 706-712.

Locomotives, Mine

Advantages and Reasons for Increased Application of Storage-battery Locomotives to Mining. Gealy, Edgar J.
Coal Age, July 26, 1923; v. 24, pp. 129-132.

Power-factor

Improvement of the Power-factor. Hartwagner, L. (In German.)
Trua, July 1, 1923; v. 4, pp. 233-238.
(Illustrated description of several types of apparatus for power-factor improvement as constructed by a Czechoslovakian concern.)

Protective Apparatus

Desirable Duplication and Safeguarding in the Electrical Equipment of a Generating Station. Sims, William F.
A.I.E.E. Jour., July, 1923; v. 42, pp. 704-705.

Radio Engineering

Disturbing Effects of the Electric Ignition Systems of Internal Combustion Engines Upon Radio Reception Aboard Aeroplanes. Kulebakin, V. S. (In German.)
Elek. Zeit., June 7, 1923; v. 44, pp. 537-541.
(Describes ordinary ignition systems for aviation engines, discussing their ill effect upon radio reception and remedies therefor.)

Ready Reckoner for Wave-length, Inductance and Capacity. Hobbs, E. J.
Wireless Wld. & Radio Rev., July 14, 1923; v. 12, pp. 472-476.

Radio Stations

Electrical Plant of Transocean Radio Telegraphy. Alexanderson, E. F. W., and others.
A.I.E.E. Jour., July, 1923; v. 42, pp. 693-703.
(An account of the equipment and of methods used by the Radio Corporation of America in its transoceanic radio business.)

Railroads—Electrification

Electric Train Operation on the German Federal Railroad and on Lines in Neighboring Countries. Wechmann, W. (In German.)
Verkehrs. Woche, June 11, 1923; v. 17, pp. 178-181.
(Describes and compares the more important electrified railroads in Germany, Austria, Switzerland, Sweden and Norway. Serial.)

Electrification of Foreign Railways. I. Switzerland. Smith, S. Parker.
Beama, July, 1923; v. 13, pp. 20-29.
(This initial installment, including maps and tables of locomotive dimensions and construction, gives details of Switzerland's progress.)

N. & W. Electrification a Good Investment.
Elec. Rwy. Jour., July 14, 1923; v. 62, pp. 45-46.
(Brief article in which are given the opinions of N. D. Maher, President of the Norfolk & Western Railway.)

Relays

Selective Relay System of the 66,000-volt Ring of the Duquesne Light Company. Sleeper, H.P.

A.I.E.E. Jour., July, 1923; v. 42, pp. 723-727.

(Author investigated several relay schemes on a ring system of duplicate feeders and gives his conclusions showing the advantages and disadvantages of the schemes considered.)

Ship Propulsion, Electric

Analysis of Claims of the Electric Drive Over the Geared Drive. Shaw, J. C.

Mar. Engng., July, 1923; v. 28, pp. 417-419, 434.

(Author endeavors to show that certain claims for superiority of electric drive over geared drive for ship propulsion are not warranted.)

Standards, Electric

Standardization of Electrical Measuring Instruments. Brooks, H. B.

A.I.E.E. Jour., July, 1923; v. 42, pp. 713-722.

(Points out the advantages of national standard specifications and discusses progress made in instrument standardization here and abroad.)

Standardized Insulator Tests.

A.I.E.E. Jour., July, 1923; v. 42, pp. 739-743.

(Report of the Insulator Subcommittee of the A.I.E.E. Standards Committee.)

Steam Accumulators

Steam Accumulators. Emanaud, M.

Chem. & Met. Engng., July 23, 1923; v. 29, pp. 149-152.

(Abstract translation of a descriptive article in *La Technique Moderne*, April, 1923.)

Steam Plants

Remote Control of High Pressure Steam Lines. Dean, Peter Payne.

Power Pl. Engng., July 1, 1923; v. 27, pp. 667-670.

(Abstract from a paper before the A.S.M.E.)

Strength of Materials

Strength of Steels at High Temperatures. French, H. J., and Tucker, W. A.

Iron Age, July 26, 1923; v. 112, pp. 193-195.

(Carbon and alloy steels compared, effect of carbon content and heat treatment, nickel and chromium steels, etc. Serial.)

Switchboards

Selection of Switchboard Equipment. Mauger, S. W.

Power Pl. Engng., July 1, 1923; v. 27, pp. 680-683.

("Considerations involved in the selection of switchboard equipment for industrial power plants of from 1000 to 6000 kv-a.")

Train Control, Automatic

Big Four Tests I. E. C. Train Control Device.

Rwy. Age, July 21, 1923; v. 75, pp. 103-106.

(Report of tests on the Indiana Equipment Corporation's automatic train control equipment.)

Water Power

Hydro-electric Possibilities of Quebec. Smith, Julian C.

Mech. Engng., July, 1923; v. 45, pp. 407-409, 429.

("The potential and actual hydro-electric development of the Province of Quebec and its probable rate of growth in the future." Discussion on p. 416.)

NEW BOOKS

Comparison of Principal Points of Standards for Electrical Machinery. (Rotating Machines and Transformers.) Nettel, Friedrich. 42 pp., 1923, Berlin, Julius Springer.

Electric Cranes and Hauling Machines. Chilton, F. E. 114 pp., 1923, N. Y., Isaac Pitman & Sons. (Pitman's technical primers.)

Electric Motors: Their Theory and Construction. Ed. 3. Vol. 1: Direct Current. Hobart, Henry M. 412 pp., 1923, N. Y., Isaac Pitman & Sons.

English and Engineering. Ed. 2. Aydelotte, Frank. 415 pp., 1923, N. Y., McGraw-Hill Book Co., Inc.

Financial Incentives for Employees and Executives. Bloomfield, Daniel, and Bloomfield, Meyer. 2 vols., 1923, N. Y., H. W. Wilson & Co.

Industrial Electric Heating. Beauchamp. J. W. 118 pp., 1923, N. Y., Isaac Pitman & Sons. (Pitman's technical primers.)

Interior Wiring Systems for Electric Light and Power Service. Ed. 2. Cook, Arthur L. 458 pp., 1923, N. Y., John Wiley & Sons.

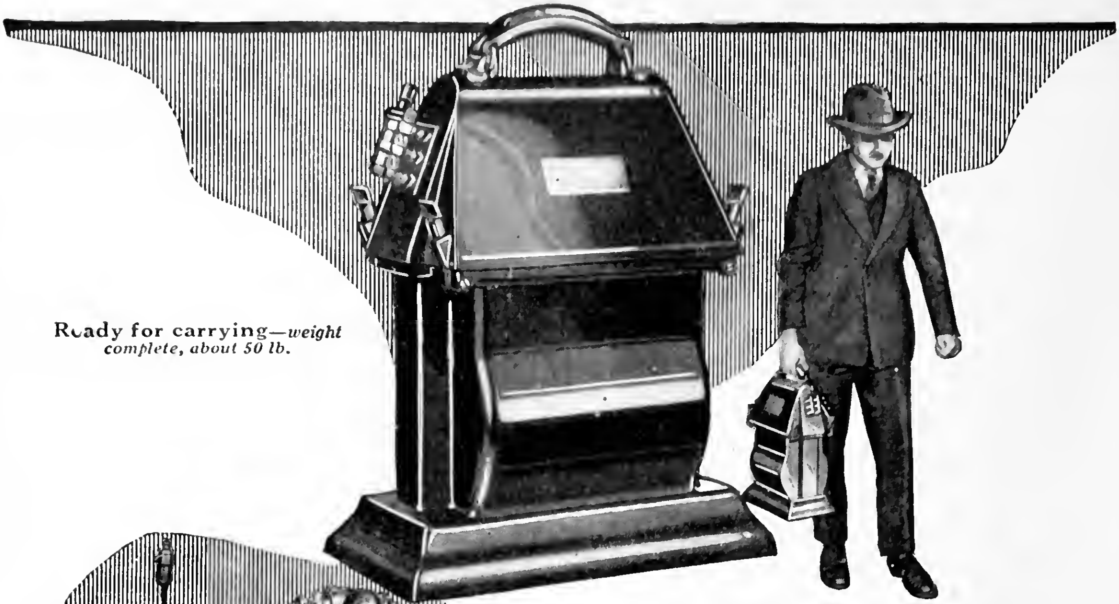
Mechanical Testing. Vol. 2: Testing of Prime Movers, Machines, Structures and Engineering Apparatus. Batson, R. G., and Hyde, J. H. 446 pp., 1923, N. Y., E. P. Dutton & Co.

Sampling and Analysis of Coal, Coke and By-products; Methods of the U. S. Steel Corporation. Ed. 2. 184 pp., 1923, Pittsburgh, Carnegie Steel Co.

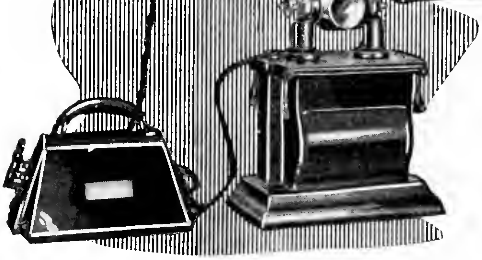
BOOK REVIEW

Atlas of the U. S. A. Electric Power Industry. By Frank G. Baum. 11 x 17 in., 34 plates. McGraw-Hill Book Co., New York and London. 1923.

In this admirable work the author gives us in graphic form complete figures of the electric power industry, power resources, and power demand of the United States. Based on the wealth of data either compiled from various sources or obtained by surveys in the field, the author suggests a comprehensive plan of developing our latent power resources and of the economical utilization of the developed power supply. According to this plan, the water power sources are to be developed and used as far as practicable, and the country divided into twelve regional power districts all of which would be inter-connected. Each regional district would be under the control of one company and this regional company would wholesale the power to smaller units for distribution. The power would be transmitted by what the author calls a constant-voltage transmission system, the voltage control being accomplished by means of synchronous condensers located every 100 or 200 miles along the transmission lines. The details of this system are given in Part II of the Atlas as well as in a recent paper read before the American Institute of Electrical Engineers. (See *A.I.E.E. Journal*, Vol. 40, pages 643-65, of August, 1921.) Mr. Baum has made a valuable contribution to the economics of the electric power industry and his work will command the attention of the financier, the engineer, the statistician and others who have an interest in power development in the United States.



Ready for carrying—*weight complete, about 50 lb.*



Ready for Service—*The set may be supplied from lighting circuits of 110 volts, 50 to 140 cycles.*

Watch your oil—
Test it regularly

To keep the same factors of safety in oil-insulated apparatus as were put there by the designer, it is necessary to maintain a high dielectric value of the insulating oil. Only a little moisture in the oil may reduce these normal safety factors as much as 50%. The only safeguard is regular testing of the oil.

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE Editor, JOHN R. HEWETT Associate Editor, E. C. SANDERS

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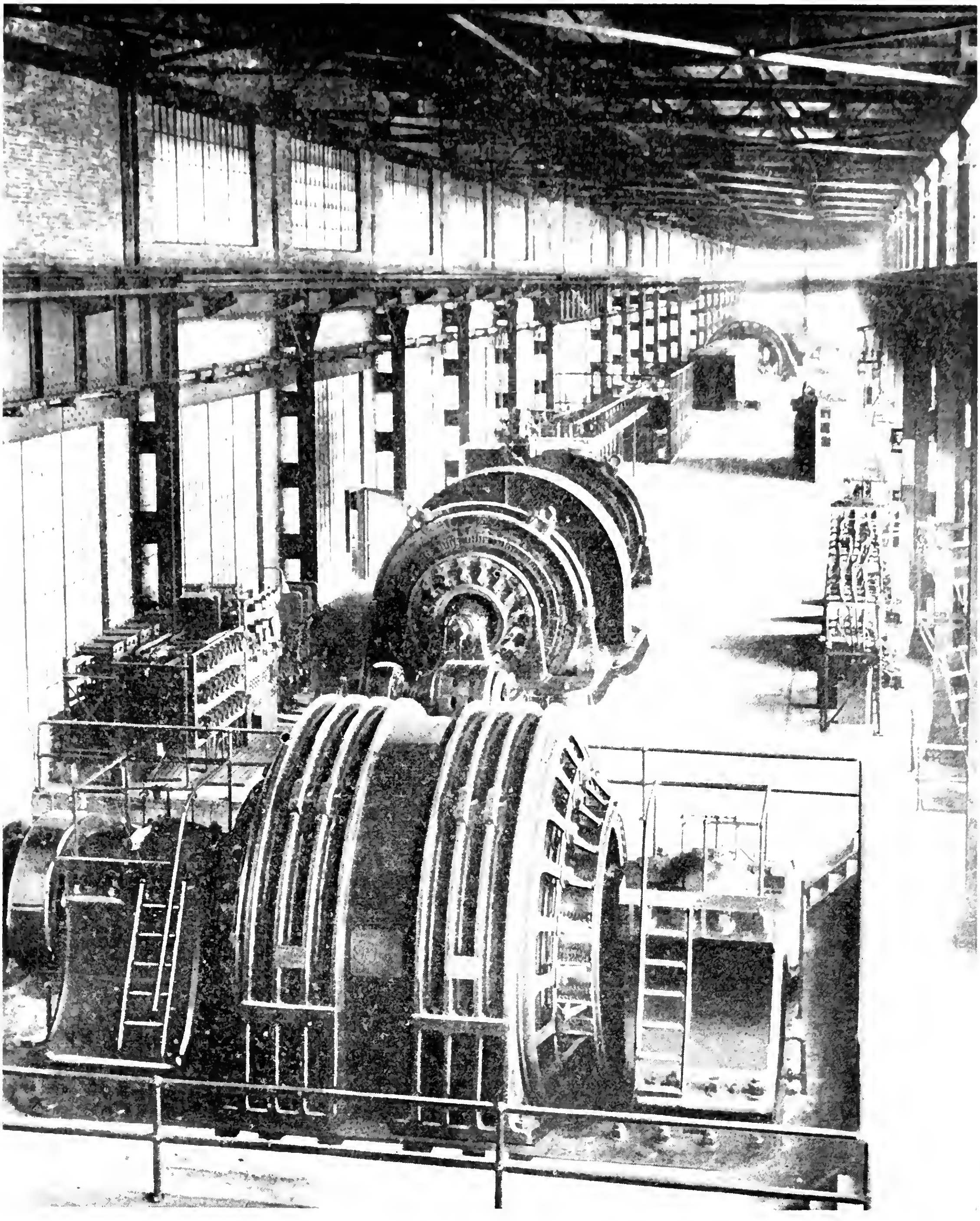

6500-h.p. Reversing Blooming Mill Motor, Flywheel Motor-generator, 4000-h.p. and 3250-h.p. Billet and Bar Mill Motors. Bethlehem Steel Co., Sparrows Point, Md.

GENERAL ELECTRIC REVIEW

IRON AND STEEL

On the occasion of the annual convention of the Association of Iron and Steel Electrical Engineers, which is to be held this year at Buffalo, N. Y., on September 24th to 29th, we devote our current issue to articles which we hope will be of both interest and use to the steel industry.

Since a very remote period iron has played an all important part in developing civilization. First the Stone Age, then the Bronze Age and *then and now* the Iron Age. The Iron Age started thousands of years before the birth of Christ and still exists today. From the days of primitive man to the present time iron has ruled the destinies of individuals and of nations.

There must be some fundamental reasons for this.

These reasons are so well put in an article in the Encyclopædia Britannica that we quote the following paragraph from this source:

"Iron, the most abundant and the cheapest of the heavy metals, the strongest and most magnetic of known substances, is perhaps also the most indispensable of all save the air we breathe and the water we drink. For one kind of meat we could substitute another; wool could be replaced by cotton, silk or fur; were our common silicate glass gone, we could probably perfect and cheapen some other of the transparent solids; but even if the earth could be made to yield any substitute for the forty or fifty million tons of iron which we use each year for rails, wire, machinery, and structural purposes of many kinds, we could not replace either the steel of our cutting tools or the iron of our magnets, the basis of all commercial electricity. This usefulness iron owes in part, indeed, to its abundance, through which it has led us in the last few thousands of years to adapt our ways to its; but still in chief part first to the single qualities in which it excels, such as its strength, its magnetism, and the property which it alone has of being made at will extremely hard by sudden cooling and soft and extremely pliable by slow cooling; second, to the special combinations of useful properties in which it excels, such as its strength with its ready welding and shaping both hot and cold; and third, to the great variety of its properties. It is a very Proteus. It is extremely hard in our files and razors, and extremely soft in our horse-shoe nails, which in some countries the smith rejects unless he can bend them on his forehead; with iron we cut and shape iron. It is extremely magnetic and almost non-magnetic; as brittle as glass and almost as pliable and ductile as copper; extremely springy, and springless and dead; wonderfully strong, and very weak; conducting heat and electricity easily, and again offering great resistance to their passage; here welding readily, there incapable of welding; here very infusible, there melting with relative ease. The coincidence that so indispensable a thing should also be so abundant, that an iron-needing man should be set on an iron-cored globe, certainly suggests design. The indispensableness of such abundant things as air, water and light is readily explained by saying that their very abundance has evolved a creature dependent on them. But the indispensable qualities of iron did not shape man's evolution, because its great usefulness did not arise until historic times, or even, as in case of magnetism, until modern times."

The above paragraph seems to give ample reason why the iron and steel industry of America is the premier industry. Today this industry is capitalized at more than nine billion dollars ($9,000,000,000).

But we are living in a Machine Age as well as an Iron Age and in an Electrical Age as well as a Machine Age; and a point which is of interest to us all is the fact that the steel industry and the electrical industry are the big twin sisters of the great American industrial family.

The steel industry employs over five million (5,000,000) horse power of electric motors and its annual consumption of electric energy exceeds eight billion (8,000,000,000) kilowatt-hours.

As each year passes we shall use more and more electrical machines and appliances in the steel industry and more steel in the electrical industry. And so these inseparable giants,—the children of man's imagination, energy and work, are destined still to rule man and the civilization he is building. J. R. H.

"Motorizing" the 33-inch Structural Mill at the Homestead Steel Works

By S. S. Wales

Chief Electrical Engineer, Carnegie Steel Company

This very valuable article shows the results obtained by just substituting an electric motor for a steam engine on a 33-inch structural steel mill at the Homestead Steel Works. A study of the summary of these results is very instructive.—Editor.

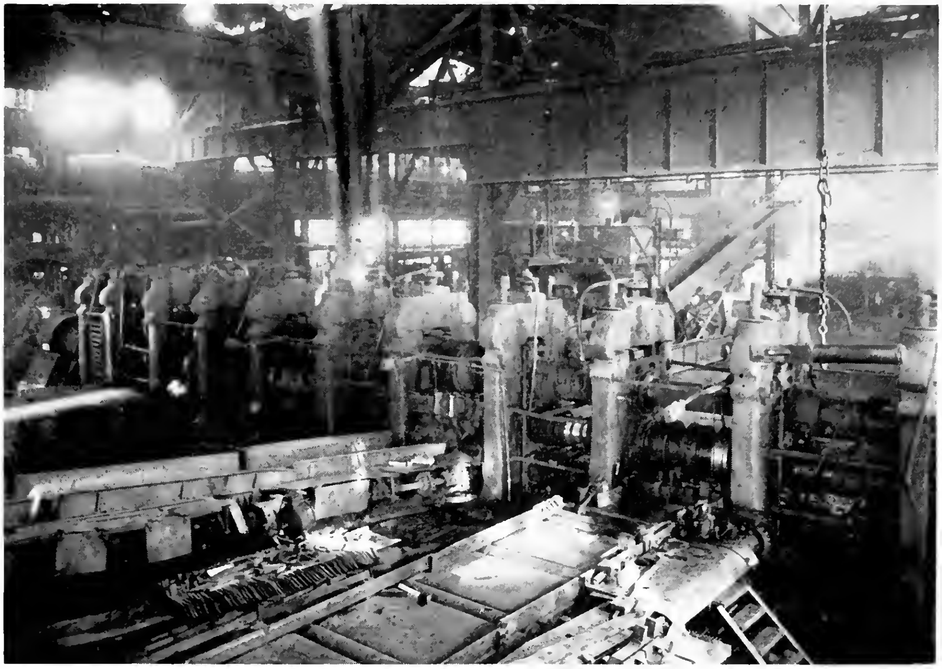

Fig. 1. Structural Steel Mill Similar to that Described in this Article

Although electric motor-driven rolling mills are now becoming quite common and attract little attention, an account of the "motorization" of the 33-inch structural mill at the Homestead Steel Works will be of interest on account of the unique feature that the installation of the motor was the only change made in the equipment.

It has been almost universally the case that the engineering department of a plant has in mind a number of changes, more or less drastic, to be made in the mill itself to improve its performance, which changes are made at the same time the motor is installed so that it is necessary to adjust the resulting benefits among several applicants each justly claiming a certain credit. With the 33-inch structural mill no change in the roll train, shoes, housings, bearings, or methods of lining up and down was made, nor were the roll sections changed in any way until after the motor had been installed and run.

Mill

This mill was installed in 1892 and is of the three-high, continuous running type, similar to that shown in Fig. 1, rolling up to 12-inch beams and 15-inch channels with such other standard and special structural shapes as fall within its capacity.

It consists of one roughing and one finishing stand normally carrying six passes in the roughing and four in the finishing rolls. The rolls are of 33-inch theoretical centers, have 20-inch diameter necks, and are 74 inches between bearings. They are made of standard material such as gray cast iron or steel.

The mill was designed to take reheated blooms or cogged shapes up to $9\frac{1}{2}$ inches by 11 inches. The bloom is received from the heating furnace and is handled on each side of the mill by electrically-driven travelling pass tables, which move parallel to the mill, receiving the out-coming piece and returning it to the proper pass until it finally is delivered to the cooling beds. The cooling beds were of ample capacity for the mill when run by the steam engine.

Engine

The engine was built by the Southwork Foundry & Machine Co. and was of the well-known Porter-Allen type, horizontal simple engine, with 54-inch cylinder and 66-inch stroke, and with a 24-foot, 180,000-pound flywheel. It was designed to work under a steam pressure of 125 pounds and atmospheric exhaust with a speed of 65 r.p.m.

Motor

The motor selected to replace this engine was a 4000-h.p., 25-cycle, 3-phase, 6600-volt machine with a synchronous speed of 83.3, illustrated in Fig. 2. The efficiency is calculated to be 94.5 per cent with a power-factor of 81 per cent and a speed of 82 r.p.m. at full load. It will deliver 4000 h.p. continuously with a rise of 35 deg. C. above the surrounding air, and 6000 h.p. with a 50 degree rise, and is capable of exerting a maximum running torque of approximately 700,000 lb-ft. corresponding to 10,500 h.p. It is provided with a cast steel flywheel 19 feet in diameter, with 16-inch face, weighing 170,000 pounds and the combined stored energy of the rotor and flywheel is approximately 18,400 h.p.-sec. An extra section of resistance sufficient to give 5 per cent additional slip is installed which is cut into the rotor circuit by means of a notch-back relay and contactor, if the load on the motor exceeds approximately 150 per cent normal torque. The motor can be started, stopped or reversed by means of push buttons mounted near the mill or by a master switch inside the motor room. While it would have been desirable to direct connect the motor and raise the speed of the mill to 83.3 it was thought best not to experiment along this line at the start so a reduction gear with a ratio of 20 to 16 was introduced between the motor and the mill pinions.

The motor was started on its regular working program during June, 1921, and has continued without interruption to the present time, the only repairs being the renewal of contact tips on certain parts of the control system due to the severe strain put on them in "wedging up" the rolls in the process of "lining" where it is necessary to successively start and stop the mill for a movement of only a few inches on the surface of the rolls.

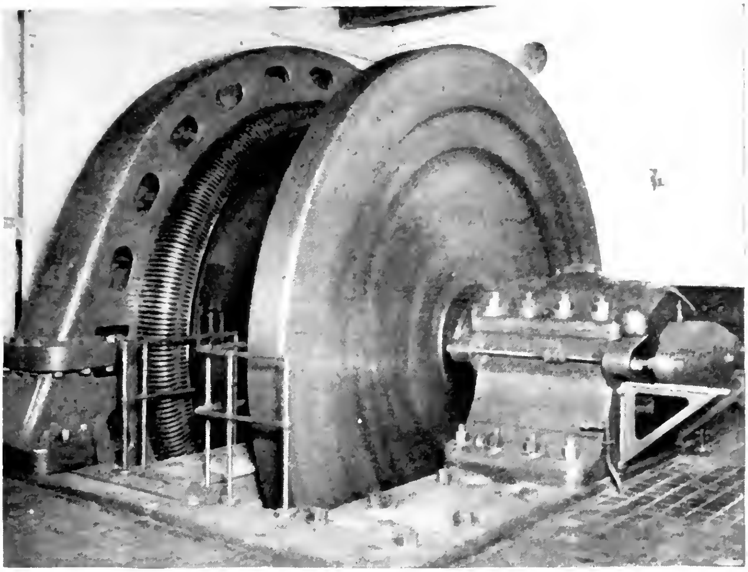

Fig. 2. 4000-h.p., 25-cycle, 3-phase, 6600-volt Induction Motor for Driving the 33-inch Mill

Results

It was noticed almost immediately that, whereas the engine used to slow down and drag on the long finishing passes, the motor held up to speed and that the finished piece was delivered to the cooling beds much hotter than before. This led to cutting the ingot into two blooms instead of into three blooms per ingot as was the former practice, further increase in weight being precluded by lack of room in the mill, as designed, to care for the extra length of the finished piece

The trouble which had always been experienced in variation in weight of section

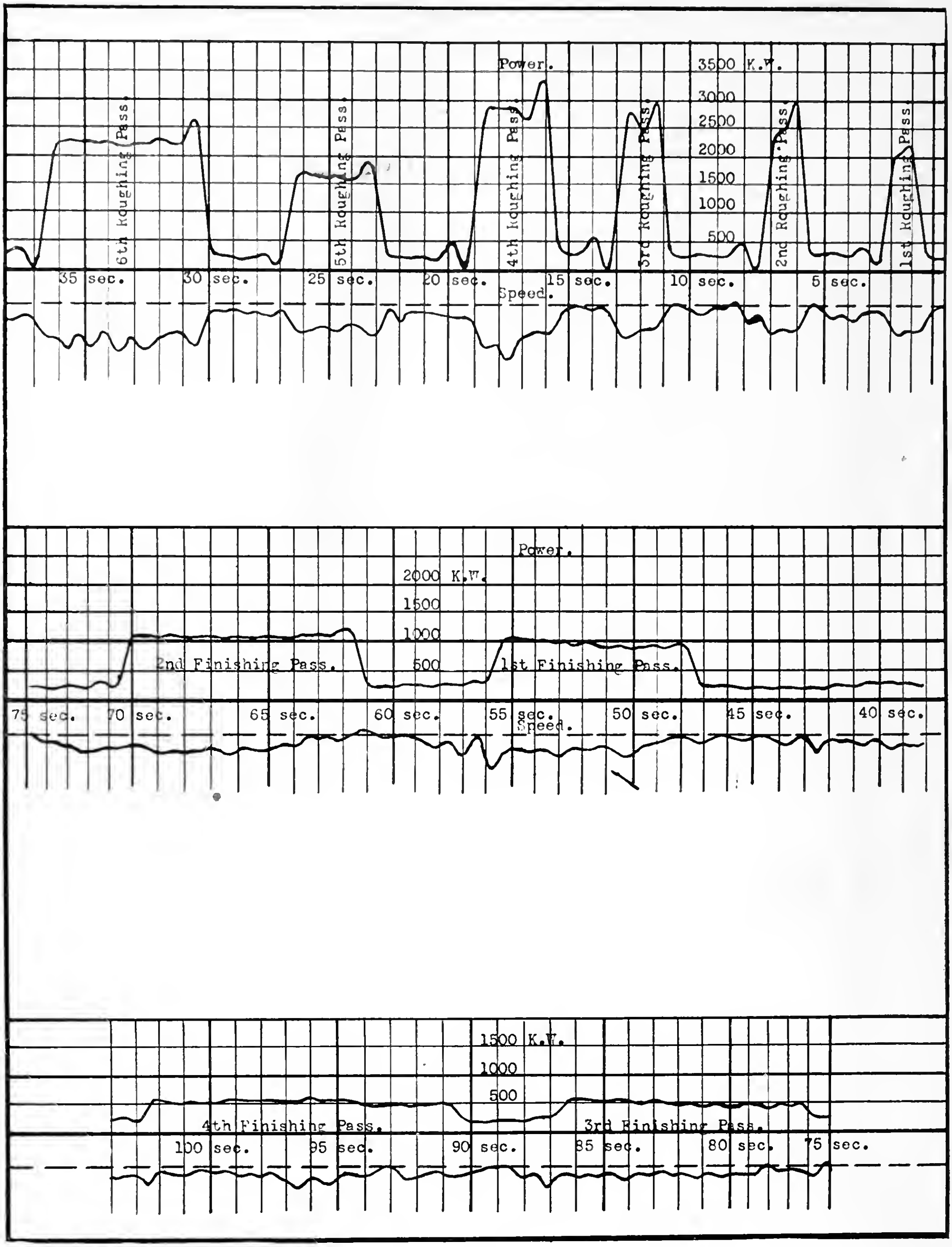
Power.
3500 K.W.
3000
2500
2000
1500
1000
500
6th Roughing Pass.
5th Roughing Pass.
4th Roughing Pass.
3rd Roughing Pass.
2nd Roughing Pass.
1st Roughing Pass.
35 sec.
30 sec.
25 sec.
20 sec.
15 sec.
10 sec.
5 sec.
Speed.
Power.
2000 K.W.
1500
1000
500
2nd Finishing Pass.
1st Finishing Pass.
75 sec.
70 sec.
65 sec.
60 sec.
55 sec.
50 sec.
45 sec.
40 sec.
Speed.
1500 K.W.
1000
500
4th Finishing Pass.
3rd Finishing Pass.
100 sec.
95 sec.
90 sec.
85 sec.
80 sec.
75 sec.

Fig. 3

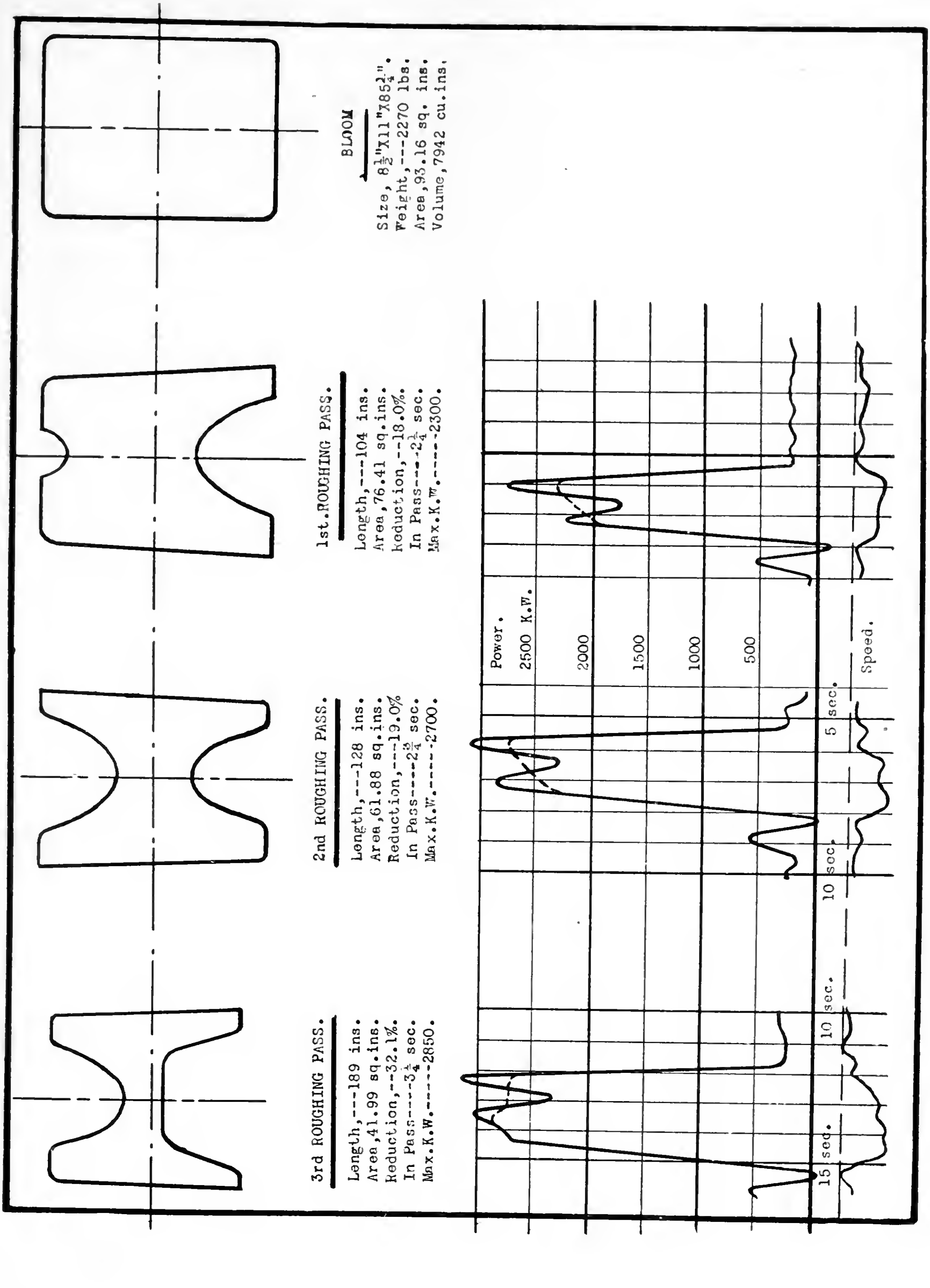
BLOOM
Size, 8½"X11"X85¼".
Weight,---2270 lbs.
Area,93.16 sq. ins.
Volume,7942 cu.ins.
1st.ROUGHING PASS.
Length,---104 ins.
Area,76.41 sq.ins.
Reduction,--18.0%.
In Pass----2¼ sec.
Max.K.W.----2300.
2nd ROUGHING PASS.
Length,---128 ins.
Area,61.88 sq.ins.
Reduction,---19.0%
In Pass----2⅜ sec.
Max.K.W.-----2700.
3rd ROUGHING PASS.
Length,---189 ins.
Area,41.99 sq.ins.
Reduction,--32.1%.
In Pass---3¼ sec.
Max.K.W.----2850.
Power.
2500 K.W.
2000
1500
1000
500
Speed.
5 sec.
10 sec.
10 sec.
15 sec.

Fig. 4

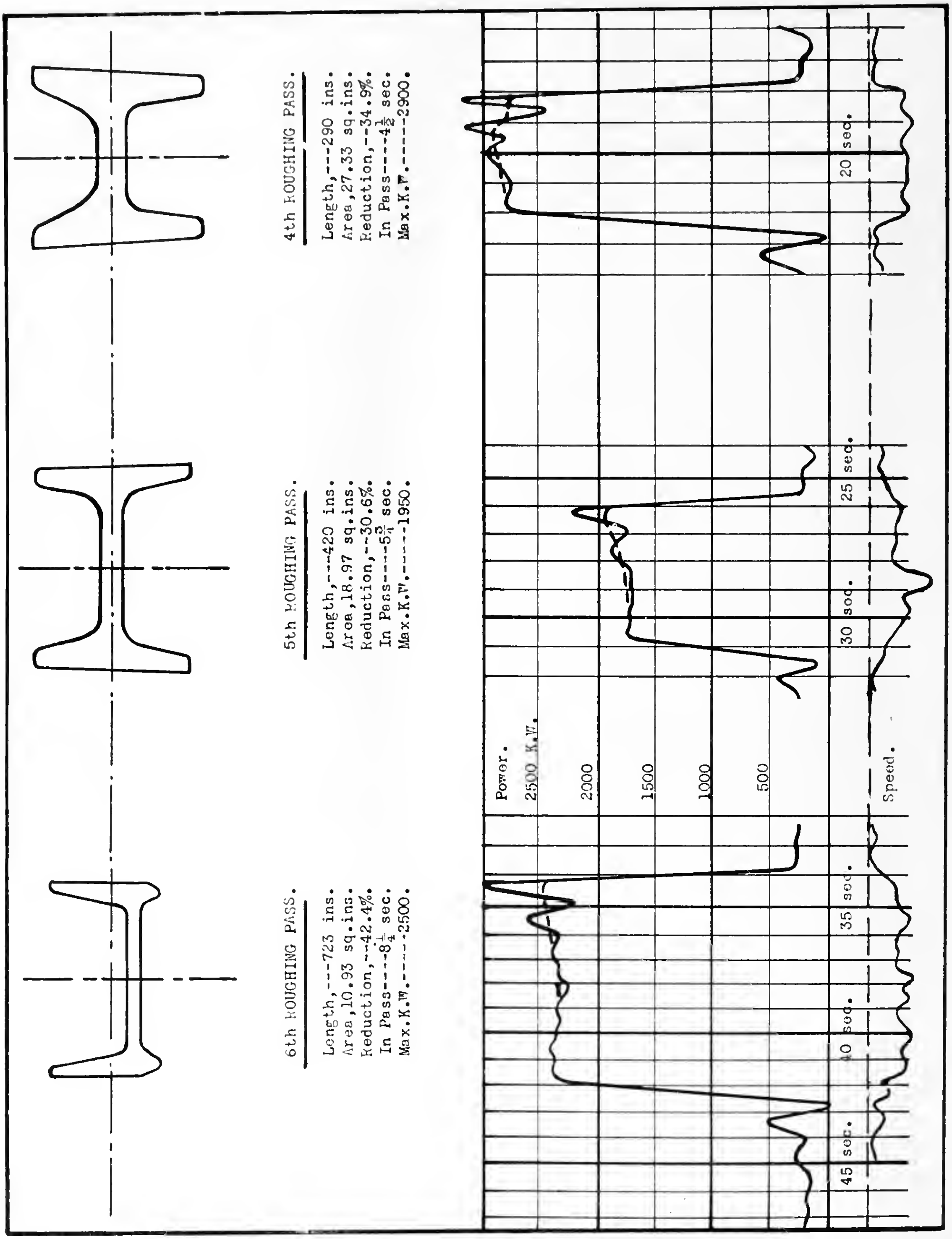
4th ROUGHING PASS.
Length,---290 ins.
Area,27.33 sq.ins.
Reduction,--34.9%.
In Pass---4½ sec.
Max.K.W.-----2900.
5th ROUGHING PASS.
Length,---420 ins.
Area,18.97 sq.ins.
Reduction,--30.6%.
In Pass---5¾ sec.
Max.K.W.-----1950.
6th ROUGHING PASS.
Length,---723 ins.
Area,10.93 sq.ins.
Reduction,--42.4%.
In Pass---8¼ sec.
Max.K.W.----2500.
Power.
2500 K.W.
2000
1500
1000
500
Speed.
20 sec.
25 sec.
30 sec.
35 sec.
40 sec.
45 sec.

Fig. 5

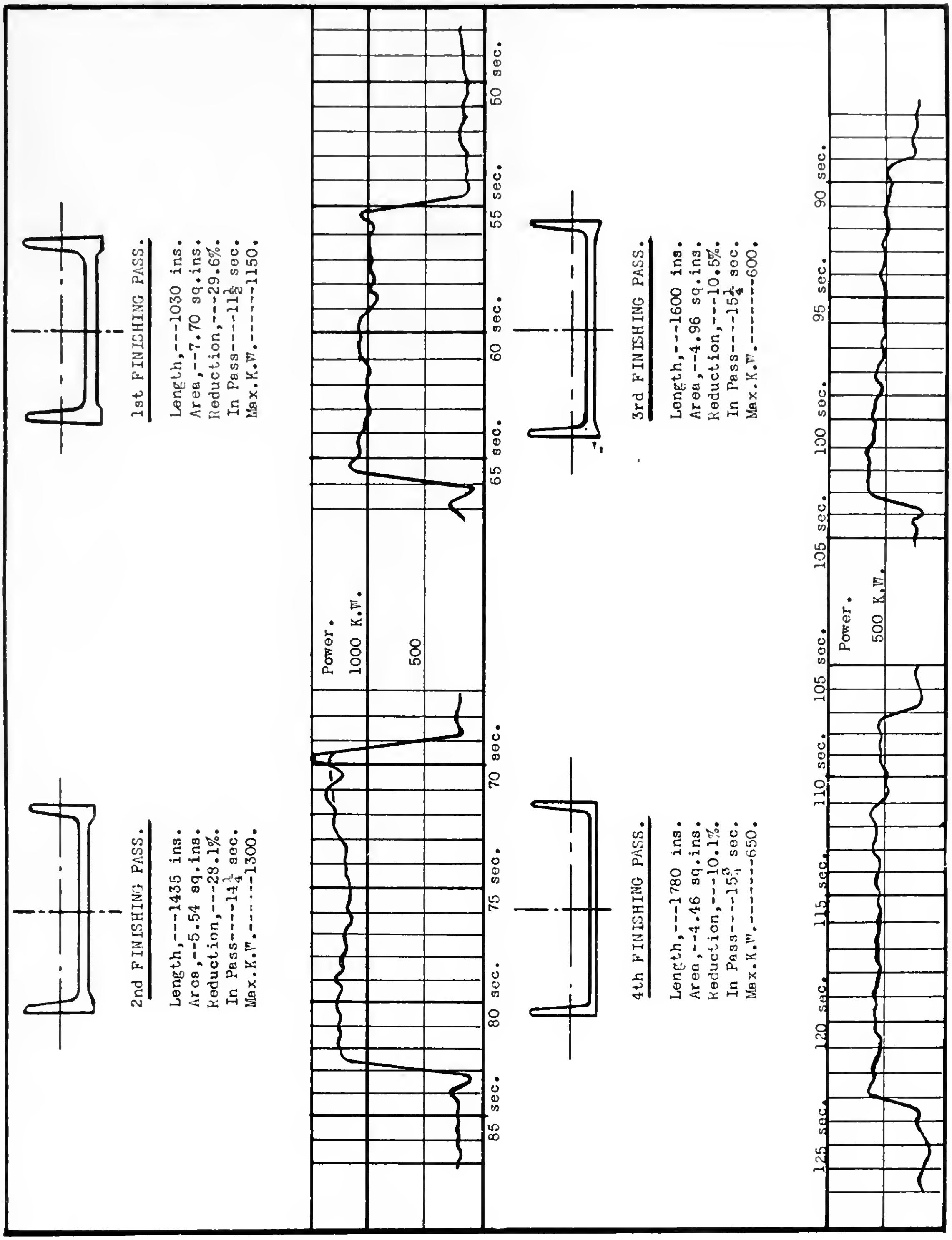
1st FINISHING PASS.
Length,---1030 ins.
Area,--7.70 sq.ins.
Reduction,---29.6%.
In Pass---11½ sec.
Max.K.W.------1150.
2nd FINISHING PASS.
Length,---1435 ins.
Area,--5.54 sq.ins.
Reduction,---28.1%.
In Pass---14¼ sec.
Max.K.W.------1300.
3rd FINISHING PASS.
Length,---1600 ins.
Area,--4.96 sq.ins.
Reduction,---10.5%.
In Pass---15¼ sec.
Max.K.W.-------600.
4th FINISHING PASS.
Length,---1780 ins.
Area,--4.46 sq.ins.
Reduction,---10.1%.
In Pass---15¾ sec.
Max.K.W.-------650.
Power.
1000 K.W.
500
Power.
500 K.W.
50 sec.
55 sec.
60 sec.
65 sec.
70 sec.
75 sec.
80 sec.
85 sec.
90 sec.
95 sec.
100 sec.
105 sec.
105 sec.
110 sec.
115 sec.
120 sec.
125 sec.

Fig. 6

sometimes amounting to several per cent was entirely eliminated, even with the 50 per cent increase in length due to using two cuts instead of three cuts to the ingot. The only difficulty encountered due to the change was that the cooling beds proved to be inadequate to care for the increased tonnage which could now be handled, so placing the limit on the output of the mill.

It was feared that the great reserve power of the motor would cause serious trouble in case of a piece being "cobbled," and that an increase in roll breakage would result, but this has not proved to be the case, the result being fewer cobbles and a considerable decrease in roll breakage. This is probably due to the uniformity of speed the motor maintains and the ample power provided, which eliminates slow rolling and serious loss of temperature during the process.

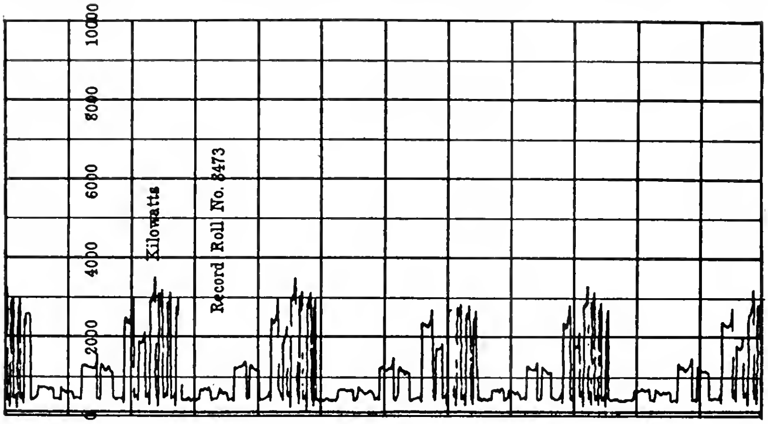

Fig. 7. Curve Drawing Instrument Chart showing the Fluctuating Character of the Load

One very noticeable advantage of the motor over any other method of driving a rolling mill is the intimate knowledge it provides the operators and roll designers regarding the power required for each pass, by means of continuous chart-drawing instruments. The flow of plastic steel under pressure is governed by so many things that the power may vary over wide limits, for reductions of area which are practically equal, especially when structural shapes are being rolled. It is possible to distribute this work over the passes to the best advantage for the mill and the finished product if the work done in each pass is known.

Charts

Fig. 7 shows a reproduction of a chart taken at 12 inches per minute with a swing of the pen equal to one half inch per 1000 kw. In this curve and those following, the wavy shape at the top and bottom is probably due to the sensitiveness of the instrument and the vibration of the ground caused by the running of the mill. The high saw-tooth form of the curve for changes from friction load to full load and back appears to be due to lack of dead beatness in the instrument allowing the pen to over swing in both directions.

Figs. 3, 4, 5 and 6 are reproductions of a chart taken at 18 inches per minute with a swing of 1 inch per 1000 kw. The speed curves at the bottom are of interest only as showing the drop in speed under load, which allows the flywheel to function. The speed curve is omitted for the finishing passes as there is hardly any noticeable decrease of speed under the power demands at this point. The curve has been spread to allow better opportunity for study and a picture of the section resulting and the data for the pass are shown above the curve. In these chart curves the time is shown in five second blocks evenly divided into single seconds which is near enough for all practical purposes. These chart curves form a basis for some very interesting study and need no discussion in this article.

Summary

As no change was made other than the installation of the motor in place of the steam engine, the electrification of this mill may be credited with the following:

1. More convenient operation due to push button control for starting, stopping and reversing.

2. Cheaper operation due to less attendance, and practically no repairs.

3. Greater tonnage and fewer pieces to handle due to the reserve power inherent in the electric motor.

4. Fewer cobbles and reduced roll breakage.

5. More uniform sections with less difference in weight of finished piece, due to quicker finishing.

6. Assistance to roll designer derived from recording chart.

Reliability of Power, a Necessity in the Steel Industry

By F. O. Schnure

Electrical Engineer, Sparrows Point Plant, Bethlehem Steel Co.

In emphasizing the importance of a continuous power supply in steel mills the author follows the steel through the mills and shows what would happen at each step if power failed. He then describes the system adopted to insure continuous power supply at all times. This contribution is written by a practical steel man in the light of long experience and will be useful to all interested in the business of manufacturing steel.
—Editor.

An uninterrupted flow of electrical energy is vitally important if the various operations in a steel plant are to function successfully. An interruption of power means chiefly loss of production, but even momentary interruptions may mean serious loss of plant equipment and extraordinary hazards to the workmen. In discussing the situation, it seems advisable to follow the raw material through the plant, noting the necessity of continuous power flow as we go. Then we may discuss the power house, transmission system, motorized equipment and their relation to the continuity of power.

The pumping station if motorized presents the most important problem. The blast furnaces, coke ovens, open hearths and mills all depend on this station for cooling water for their stacks, doors, valves, rolls, etc. Steam standby equipment, for use in case of power failure, is not satisfactory unless installed in adequate capacity to maintain the standard water pressure, otherwise the upper parts of the blast furnace suffer. Booster pumps, either steam or electrically driven, from other sources of electrical supply, at certain strategic points relieve the situation somewhat, but are not a definite insurance against burnouts, as pump men for starting this equipment are not always instantly available.

The ore wharf and field is not seriously affected by power interruption provided braking on trolleys is done by air or hand, and the lowering of buckets by the use of dynamic circuits. However, when power fails because of faulty contactor operation, it is possible to drop a bucket in a ship or car and do serious damage. Track clamps should be set by gravity, so that a combination of high winds and loss of power would not allow the traverse motion of the bridge to get beyond control. A prolonged interruption of power may mean a considerable loss of product throughout the plant if the bridges are not able to keep the blast furnaces stocked, and in holding up the unloading of ships or cars may mean the accumulation of considerable demurrage.

A power interruption in the coke ovens affects principally the by-product plant, so that any revenue such as obtained from the sale of illuminating gas may be lost. If this gas is used as a fuel in other operations of this plant, these operations will also be delayed. Cooling water is also very important in this plant, and where these pumps are driven electrically, the situation could become very critical. An interruption of any length would of course limit the production of coke, which would in turn limit the output of pig iron at the blast furnaces.

At the blast furnaces, a momentary interruption of power, stopping the flow of cooling water through the stack plates and valves, may cause damage to the equipment amounting to thousands of dollars. In the blowing engine department, failure of power on the motors driving the gas washers would shut down the blast furnaces, by stopping the flow of gas to the blowing engines. An interruption of power on the pumps circulating the cooling water for the gas engines will cause hot cylinders and exhaust headers, and require an immediate shutdown of these units. Untimely re-entrance of water into the cylinders and headers may cause cracks that will require considerable time and expense to repair. When power fails the most dangerous place in the plant is in this gas engine department, as failure of the engines to function normally releases live CO to the atmosphere in quantities that makes work in restricted areas extremely hazardous.

In the open hearth, a slight interruption of power affecting the cooling water will warp the coolers on the doors and burners and if not causing instant failure will affect the metal, so that in a few days it may become necessary to change 75 per cent of all such equipment subjected to this loss of water. This loss of equipment is not serious of itself, but affects production which may mean several hundred dollars per furnace per hour. The secondary situation in the open hearth lies in loss of direct-current power to operate the cranes, mixers and tilting furnaces. It is very often possible when power fails while pouring a ladle of metal to move the line of ingots by a locomotive and save any loss of product or serious inconvenience. When the loaded ladle is being raised to the pouring position, and the power fails, the situation is not quite so simple. If of long duration, heavy sculls result requiring expensive handling and re-melting. If the power fails while the mixer is in the "down" position, and the operator is unable to raise it, a very nasty spill occurs which means a considerable amount of money to clean up. The same situation prevails in respect to the tilting furnace.

In the rolling mills, there is the possibility of burning out valve coolers, furnace door frames and bearings when cooling water fails. Power failures which catch soaking pit cranes and furnace chargers, with the ram in the pit or furnace, may be the cause of castings warping and the wiring burning up. In continuous mills driven by large induction motors, a partial failure of voltage causing the control to trip or contactors to drop out may cause stickers in the mills, which require from one to three hours to clear up. In addition the hot steel warps and cracks the chilled rolls so that roll depreciation may be very high. On sheet bar mills, an interruption of a few seconds on the pinch rolls, delivering the sheet bar to the bar piler, may mean cobbling the entire ingot. It is important that some mills have a constant voltage as well as uninterrupted supply of power.

Having reviewed the things which may happen to cause loss of production and equipment, both of which entail considerable expense, we can now pass to the power house to study ways and means of preventing these failures.

The power supply for steel plants may be derived from gas-engine-driven generators, steam turbines or central station power or combinations of two or all; and it is worth while to make a study of the reliability of each source of energy. Gas-engine-driven generators unless installed in sufficient number and operated below their rating have very little overload capacity, and may easily stall under grounds or heavy overload unless proper relay protection is afforded. Gas engines may also fail because of gas trouble in the furnaces, from low fuel value of the gas and from overspeed and ignition trouble.

Steam turbines are probably the most reliable provided the boilers are equipped to burn fuel oil or coal in case of blast furnace gas failure.

Central station power is usually on a par with steam turbines, when the central station system does not cover too much territory or overload its transmission system and generating stations. When the central station extends over considerable territory, lightning disturbances in the form of surges are apt to be reflected over the entire system, in the same way cable failures cause voltage variations, which are disastrous to continuous mills employing large motors on their main drives.

There are, however, few steel plants which employ only one of the above systems, usually a steel plant has either gas engine or steam turbine equipment and uses central station power to make up what they cannot produce themselves. Thus it means the steel plant has all its own trouble to guard against plus the reflection from the central station. It is important then that some relay connections between the two systems be employed, so that in case of failure of the one the service on the other would not be seriously affected.

The Sparrows Point plant is operated by six 4000-kw. gas-engine-driven units augmented by feeders totaling 20,000 kw. from a central station. The plant has a maximum demand of from 25 to 35,000 kw. With no total outage during the past six months we have had 24 disturbances where the voltage dropped below 75 per cent of normal, four of which originated in our plant. One was caused by a locomotive crane grounding the lines, one by a 1000 h.p. motor grounding, one by a 1400 h.p. starting compensator failing and one by a circuit blown down by a storm. Of the central station disturbances, five were slight surges, three were outages from overload, and twelve were surges of sufficient intensity to trip either a low voltage or reverse current relay. In addition to this our plant system was separated from the central station system nine times in order to avoid surges due to storms and lightning disturbances. In the power house, the vital load consisting of the power house auxiliaries and the central pumping station, making a total load of 5000 kw. is placed on the house bus along with two generators. The remainder of the plant load is placed on the main bus with the other generators and the central station power.

The bus tie connects the two and has relay protection consisting of low voltage and a predetermined amount of reverse power from the house bus to the main bus. It has been demonstrated that a reflection from a surge from the central station system, or about our own plant, will cause this bus tie to open under either low voltage or rush of current from house or main bus and leave the vital plant load to be served by two generators. This protection has proven very satisfactory functioning without a failure during the last year. As an extra precaution in case of this relay failing, it is the practice of our operators, in the face of an approaching storm, to open the bus tie and run with these auxiliaries as a two engine load.

Power interruptions from the power house may also come from overloading the central station feeders and to prevent this occurring, an overload relay has been installed on the central station system, so that when the load on this circuit reaches about 90 per cent of its tripping value, the relay functions, opening the control circuit of power on the approach tables in one of our mills thus stopping the flow of steel. This, in the course of a fraction of a minute, automatically cuts off 3000 kw. load and if required, 30 seconds later 4000 kw. and in about three minutes 3000 kw. more when the mill is running empty. In case further relief is required, push buttons operated from the power house open the circuit breakers on the main motors in other mills and provide means for the operator to lighten the plant load without tripping the circuits and losing the auxiliaries, before the central station power reaches a point where it might open from overload.

The transmission system presents a very important link in the chain which our electrical department forges in order to maintain continuity of service. In our plant, rather than maintain a multiplicity of circuits from the power house to the various mills, a double loop system has been installed, which virtually extends the power house bus to the various mills and substations. This system has been very satisfactory, being substantially built of the best equipment, and enough cable capacity has been installed so that no trouble can possibly arise from overload. At each load point, this double loop consisting of one million circular mil cable per phase, enters the switching towers and passes through two oil switches, as a part of the transmission system. The mill feeders connect to the loops between these oil switches and relay protection is so afforded that when trouble occurs on any section, the system will automatically clear itself.

After three years operation of these 6600-volt circuits, we have had but three failures on this system, two being caused by lightning flashing over the entrance bushings, both occurring before the ground wire was installed and one by a rat grounding a disconnecting switch. Another double feeder passing over the coke plant to the main pumping station, although well insulated, got in trouble so often from dirt, gas and loose sheathing blown from conveyors by high winds that a single circuit consisting of a three-conductor cable well insulated by cambric and armored by a steel tape was installed. This installation has proven very satisfactory.

All the protection incorporated in the power house and transmission system is not of much value unless the distribution system permits of flexible operation. In this plant, the secondary circuits of 550-volt alternating current and 250-volt direct current practically follow the 6600-volt loop so that in any mill or substation this service can come from the low voltage loops. Besides permitting of urgent repairs without shutting down any mill equipment it allows taking motor-generators and transformer banks out of service and laying off sub station operators during inactive periods.

The electrical department's responsibility in maintaining power on any service does not end with maintaining voltage at the point of consumption. Power is of no value unless converted into work through motors and switching equipment well maintained. In the first place all equipment should be of rugged construction, in the second it should be well cared for and in the third, suitable spares should be carried for emergency replacements.

If all three ideas work hand in hand from the power house through the transmission system to the motorized equipment the steel plant should have reliable power.

Direct-current Power Generation for Steel Plant Loads

By Ernest Pragst

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The selection of a system to provide an adequate amount of direct-current power for operating steel mill auxiliaries often presents a difficult problem to solve. The author analyzes the pros and cons of the various methods available and makes recommendations to suit different needs.—Editor.

As each new plant is designed the most suitable method of obtaining an adequate source of continuous current power for operating the numerous auxiliary drives throughout the plant has to be determined. Much has been written on this subject, but it might be well to present again the characteristics of the several systems of deriving this form of power. The following discussion will approach the subject primarily from the point of view of the steel plant electrical engineer, will concern itself largely with apparatus suitable for use in such industries and will deal with the operating characteristics of the types of machines involved rather than with the problems of their design and manufacture.

Characteristics of Steel Mill Loads

It is not possible to set forth in detail and with accuracy the characteristics of steel plant loads in a form that will be applicable to all. One can only speak in generalities, in terms of tendencies and those plants representative of a large and influential group. The steel mills, as do all other classes of industrial establishments, vary greatly one from another in size, modernity, principle of operation, and administrative policy. Further variables are introduced by location, the raw materials used, products manufactured and the like. With a realization of these limitations in mind it may be said that in general relatively large amounts of electrical power are used in their manufacturing processes and in the form of both a-c. and d-c. energy, the former predominating in quantity. The greater part of the a-c. power is usually consumed by a relatively few large motor installations and in some cases electro-thermal applications. On the other hand the d-c. power is used to actuate a proportionally large number of relatively small auxiliary drives. This classification excludes from the d-c. group such applications as reversing blooming mill drives, etc., which are d-c. operated. These may more truly be classed with the a-c. loads for they are invariably operated as a unit with and supplied with power from a special a-c./d-c. motor-generator set which in turn is fed from the plant a-c. power source. So, we have to deal with two forms of electrical power, a-c. and d-c., and it is evident that we must consider them in their interdependence if a true appraisal of the merits of the apparatus best suited for the generation of either is to be arrived at.

As a rule the points of power usage are distributed over a relatively large area and the generating capacity confined to a single point. The locations of the drives are determined by the layout of the mills which in turn are so arranged as to permit a free and easy flow of raw materials and those in process throughout the plant. The locations of the loads usually have only a secondary influence in determining the selection of the generating site or sites. The controlling influences are the sources of fuel and water supply as electrical energy can be more satisfactorily transported than either. For economic reasons, where possible, power is generated in any given plant at a single point. This applies to those plants which generate their own power. In those cases where power is purchased, the locations of the principal loads can influence to a greater extent the placing of the primary substation and the distribution from it.

The electrical characteristics of the a-c. loads of representative plants are very typical. They are of twenty-four hour duration each day fluctuating greatly with unusually high momentary recurring peaks and of low power-factor. The operating potential is generally either 2300 or 6600 volts with a few exceptions as high as 13,200 volts. The voltage selection is determined by the minimum which efficient transmission permits and the maximum for which induction motors of economic design and good electrical characteristics can be built. Three-phase operation at either 25 or 60 cycles is almost universal.

The d-c. load is in operation also twenty-four hours a day. It is of a fluctuating nature but the fluctuations are not as great as in the case of the a-c. load, due to the effect of the diversity factor of the numerous small loads.

The generating voltage for this class of load has been standardized. It is 250 volts.

Continuity of service is essential. An interruption in the power supply might result, not only in a loss of production, as in some industries, but as well in the loss or deterioration of materials in the process of manufacture, the failure of apparatus and a serious hazard to the lives of employees.

Sources of D-c. Power

There are several sources from which d-c. power may be derived.

(a) Through direct generation, namely by driving d-c. generators by prime movers.

(b) Through a-c. generation and a-c./d-c. conversion using for the conversion:
  (1) Motor-generator sets either induction or synchronous motor driven.
  (2) Synchronous converters with transformers.
  (3) Mercury arc rectifiers.

As a rule the derivation of d-c. power through direct generation is not economically desirable. For its efficient production in this manner large capacity units located at a single point must be employed. When this is done, the distribution of the output at its low voltage presents a problem for which a satisfactory solution does not seem possible. To divide the generating capacity into numerous relatively small machines located near the load centers, thereby overcoming the difficulties of distribution, presents a more numerous group of problems. In such a case the efficiency of generation will be decidedly decreased and its cost increased. Together with these disadvantages are coupled the problems of getting steam or fuel and water to and from the prime movers, plus those of an operating nature which must necessarily ensue. It must be concluded that, excepting some peculiarly special cases, the direct generation of d-c. power is accompanied with such difficulties as must always act as serious detriments to its selection as a means of securing this form of energy. The limited number of this class of installation throughout the country confirms this conclusion.

Where the required d-c. power is obtained through a method of a-c./d-c. conversion, the whole plant's electrical demand may be produced in a single a-c. generating station consisting of a relatively few large capacity high economy machines. This represents a type of generating station in which the highest generating efficiency can be obtained with a minimum investment and operating cost. The conversion capacity may be composed of relatively small units located near the load centers and fed with a-c. power from the central a-c. source at a voltage which will produce a negligible loss in the transmission system. The d-c. distribution losses may thus be inexpensively reduced to a reasonable minimum. It is this possibility which has brought this method of obtaining the d-c. power requirements of steel plants into almost universal use as against that of direct generation.

The two most common methods of conversion are through the use of motor-generator sets and synchronous converters with transformers. These will be considered at length later.

A third method is based on the employment of mercury arc rectifiers. Our interest in these for steel mill work is more academic than practical. In their present form their characteristics are such as to limit their field of economic application to those high voltage (600 volts and above) d-c. uses where high efficiency at both light and heavy loads is essential. Electrical losses in a rectifier vary with the current rectified and are substantially independent of the voltage. Hence their efficiency at low voltages is not so different from that of motor-generators and converters, but increases rapidly with an increase in voltage, surpassing that of this class of apparatus at the higher voltages. When considered with their transformers, the a-c. input to the transformers used with rectifiers is of high power-factor, roughly 95 per cent. As their price at present is greater than that of either motor-generators or converters, their efficiency not materially greater and their power-factor lower, when designed for service at the potentials usually met with in the class of service under consideration, there has been no incentive to consider them seriously for installation in steel plants as yet.

Motor-generator Sets *versus* Synchronous Converters*

For the practical business of a-c. d-c. conversion in steel plants the choice of system becomes a selection between synchronous converters with transformers and motor-generator sets or more specifically, synchronous motor-generator sets. The induction motor-driven set may at once be eliminated from

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* For a further discussion of this subject with particular reference to motor-generator sets and synchronous converters for railway and d-c. lighting service see "60 Cycle Converting Apparatus," by J. L. Burnham, GENERAL ELECTRIC REVIEW, May, 1920, p. 392.

consideration due to its lower power-factor and the fact that the induction motor possesses no peculiar characteristics which better adapt it to generator drive than does the synchronous motor.

In making a comparison between motor-generators and converters, no consideration need be given to such questions as relative heating, commutation, overload capacity, etc. These are strictly machine design problems. Both classes of apparatus can be built to meet the same requirements in these respects. Obviously, a true comparison must be based on the assumption that these characteristics are alike in both classes of equipments.

The synchronous converter as commercially designed is inherently a unity power-factor machine. Operation under loads approaching rated output at power-factors varying more than a few per cent from unity will result in serious local heating within the armature and poor commutation with its accompanying detrimental effects. The synchronous motor may without difficulty be constructed for operation at any power-factor with a decreasing cost per kv-a. of rated input for an increase in input. As power-factor correction is so desirable in most installations, it is almost universal practice to design the motors of synchronous motor-generator sets for 80 to 85 per cent leading power-factor operation. Where system power-factor correction is felt necessary, the motor-generator set is decidedly superior to the converter.

As regards simplicity of operation, there is little difference between the two classes of apparatus with the motor-generator having a slight advantage if any.

Maintenance likewise should not differ greatly. Here, too, engineers are inclined to favor the motor-generator set slightly due to the converter requiring two sets of brushes. On the other hand, the converter with transformers should be less liable to electrical break-down of insulation as a result of abnormal voltages impressed on it by such phenomena as lighting. This is due to the ability of the apparatus designer to inexpensively augment the insulation at vulnerable points. It is accomplished by increasing the insulation on the end turns of the transformer primary windings, the ends of which are connected to the incoming lines and so must withstand the shock due to high voltage and frequency, particularly where the lines are exposed to severe lightning disturbances. The synchronous motor armature winding does not lend itself to such a simple precautionary measure.

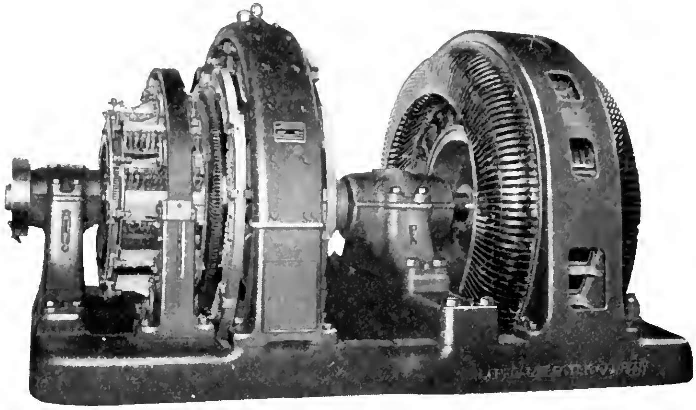

Fig. 1. Motor-generator Set. Generator Rating 1500 kw., 514 r.p.m., 250 volts. Motor Rating 2100 kv-a., 514 r.p.m., 6600 volts

Flexibility of voltage control is superior in the case of the motor-generator set to that of the converter. The d-c. potential of a motor-generator set can be controlled and varied at will irrespective of voltage conditions on the driving a-c. system. In the case of the ordinary converter it is a function of the a-c. voltage and varies directly with it. There is a slight compounding possible where compound converters are operated with high reactance transformers due to the possibility of varying the potential drop through the transformers and over the lines by changing the power-factor of the input to the converters within the limited range possible. It is usual to so adjust the compound and shunt field excitations that full load operation is at unity power-factor or slightly leading, and at low loads lagging, thus reducing the potential drop over the a-c. circuit and up to the converter rings to a minimum at full load and increasing it to a maximum at light loads, thereby approaching or in some special cases possibly slightly exceeding flat compounding. Through the introduction of a synchronous booster or induction regulator the control of the average d-c. voltage becomes possible but at the penalty of additional cost and a decrease in efficiency.

Wherever converters are used, there is an electrical connection between the a-c. and d-c. systems. Disturbances on one are reflected in the other. Change in frequency affects the voltage of the motor-generator; while change in primary a-c. voltage is transformed through the converter. In the case of motor-generator set conversion there is no electrical connection between the two systems. The only tie is mechanical through the shafts of the sets, and so there is no possibility of reflection from one system to the other of momentary abnormal electrical voltage and current variations from the normal which are constantly occurring in the class of service under consideration. It is this dependence of d-c. voltage upon that of the a-c. source which makes it undesirable to attempt to parallel on the d-c. side converters with generators, except in special cases where the a-c. source of supply is known to be substantially free from voltage fluctuations.

In some few cases it is felt desirable to be able to meet emergencies through an inversion in the operation of the conversion apparatus, namely through conversion from d-c. to a-c. Here, the synchronous machine will be capable of carrying a load having a power-factor at least as low as the power-factor rating of the synchronous machine when operating as a motor and equal to the rated output of the d-c. machine less the set losses. The converter under such a condition is at a disadvantage due to its inability to carry loads approaching its capacity at power-factors varying materially from unity.

Where the a-c. voltages do not exceed those usually met with in steel plant practice, in which case it is assumed that the synchronous motor may be built for operation at the system a-c. voltage, there is not a great difference in price between the two classes of equipment. Synchronous motor-generator sets with complete a-c. and d-c. control will cost substantially the same as converter outfits, including transformers, a-c. and d-c. control and the bus material between the transformers and converter collector rings in the case of the smaller sizes (100 to 175 kw. capacity). As the size is increased the converter equipment becomes proportionately less costly, reaching in the case of the larger machines, a value of 85 to 90 per cent of that of the motor-generator set with switchboard. These ratios are based on an a-c. potential of 2300 volts in the smaller sizes and 6600 volts in the larger ones, also 250 volts d-c. throughout. An increase in a-c. potential will lower the ratio slightly in the larger sizes and to a greater extent in the smaller ones as the increase in cost of transformers with an increase in voltage is less than in the case of synchronous motors. So, where the smaller medium a-c. voltage equipments are concerned, price need not be considered in determining their selection, but in the large ones, where a difference exists between the two, favoring the converter, it must necessarily be taken into account and act as one of the factors influencing choice.

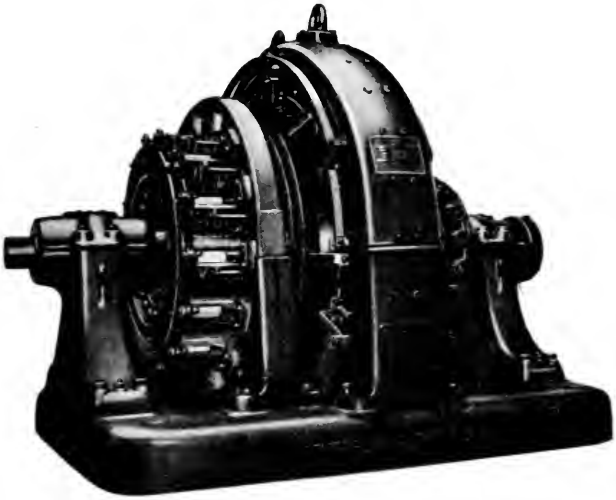

Fig. 2. Synchronous Converter, Rated at 1500 kw., 514 r.p.m., 250 volts

The synchronous converter along with its complementary apparatus has a higher efficiency than the motor-generator set throughout the whole range of sizes, the ratio of efficiencies varying from, roughly, 94 to 96 per cent in the smaller sizes to 96 to 97 per cent in the larger.

The floor space required by large converters with transformers is only 5 or 6 per cent greater than that required by motor-generator sets but in the case of the smaller sizes this will be increased as much as 30 to 40 per cent.

The relative weights of the two classes of equipment are substantially the same except in the smaller sizes where the converter with transformers is slightly heavier.

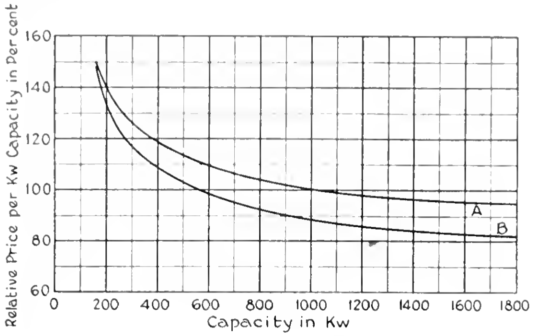

Fig. 3. Relative Price Per Kw. of Capacity Expressed in Per Cent for Motor-generator Sets and Synchronous Converters with Transformers

Curve *A* Motor-generator Sets with Complete Switchboard
Curve *B* Synchronous Converters with Transformers, Complete Switchboard and Alternating-current Bus Material between Transformer and Converter

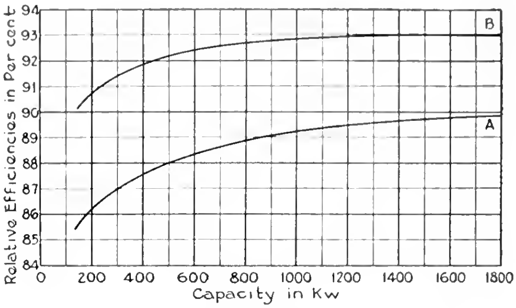

Fig. 4. Relative Efficiencies Expressed in Per Cent for Motor-generator Sets and Synchronous Converters with Transformers

Curve *A* Motor-generator Sets
Curve *B* Synchronous Converters with Transformers. The Losses included are those of the Converter, Transformer and Alternating-current Bus between the Transformers and Converter

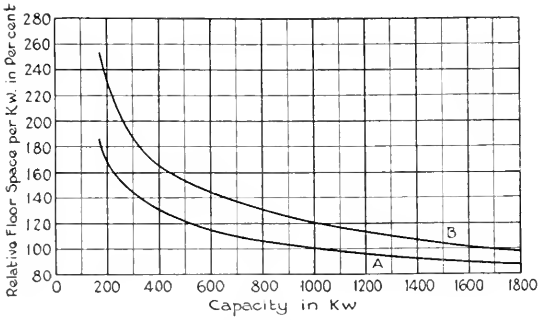

Fig. 5. Relative Floor Space Per Kw. of Capacity Expressed in Per Cent for Motor-generator Sets and Synchronous Converters with Transformers

Curve *A* Motor-generator Sets
Curve *B* Synchronous Converters and Transformers

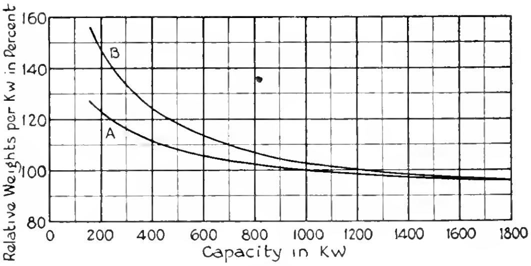

Fig. 6. Relative Weights Per Kw. of Capacity Expressed in Per Cent for Motor-generator Sets and Synchronous Converters with Transformers

Curve *A* Motor-generator Sets
Curve *B* Synchronous Converters and Transformers

So that the reader may better visualize certain of the more important relations between the two classes of equipment a number of curves have been included. Fig. 3 shows the relative price per kw. of capacity for motor-generator sets and synchronous converters with transformers; Fig. 4, the relative efficiencies; Fig. 5, the relative floor space required; and Fig. 6, the relative weights. These curves are based on apparatus having a continuous rating as defined by the A. I. E. E. and designed to operate from a three-phase source, 60-cycle, 2300-volt in the smaller, and 6600-volt in the larger sizes, and to deliver 250-volt d-c. power. The power-factor of the motor in the case of the motor-generator sets is taken as 85 per cent. In determining the curves the characteristics of numerous equipments were plotted and a curve drawn through the mean of these values. As one might naturally expect certain designs have values which fall well off the curve; however, there were enough varied designs to define the curves fairly well as shown. Although the actual values for 25-cycle apparatus and that having a nominal rating will differ somewhat from those of the machines which form the basis of the curves, namely an increase in price, weights and dimensions, the relative values as shown in the curves are fairly representative of this class of apparatus as well.

Summary

It is usually more desirable to generate the whole power requirement of a steel plant in the form of a-c. energy and convert sufficient of it to meet the d-c. need than to produce the a-c. and d-c. power independently. Of the several possible methods of conversion those employing motor-generator sets and synchronous converters with transformers are the only ones which, in the present development of the art, warrant serious consideration.

It is essential to maintain continuity of power service on both the a-c. and d-c. systems. Substantially constant d-c. potential is desirable. The a-c. load is a greatly fluctuating one of low power-factor. Where blast furnace gas and waste fuel is burned the cost of power production is relatively low. Comparing these characteristics of the loads with those of motor-generator sets and converters, it appears that in all of its major characteristics with the exception of price and efficiency the motor-generator set is superior to the converter, and where the cost of power is low as is often the case, the difference in efficiencies is discounted to a great extent. This leaves the decision to be drawn largely from a comparison between the difference in cost of the two classes of apparatus, which favors the converter equipment, and the value placed on the power-factor corrective capacity of the motor-generator set, its flexibility and its ability to maintain an electrical segregation of the a-c. and d-c. systems. From the ratio of the installed capacity in synchronous motor-generator sets to that in synchronous converters now operating in steel plants one is led to conclude that most steel plant engineers appraise the more advantageous operating characteristics of the former higher than the lower price and better efficiencies of the latter for steel plant loads.

Switching Apparatus in Steel Mills

By G. H. Jump

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The author notes and points out the similarity and difference between city and steel mill power equipments. He then discusses the layout of power supply circuits for steel mills and gives many useful details regarding switching equipment.—Editor.

Electricity in the iron and steel industry has advanced from the position of a necessary, but minor, auxiliary to that of a major element in plant operation. In the modern steel plant nearly every mechanical power requirement, from the handling of coal and ore to the loading of the finished product, is supplied by electric motors receiving energy through the plant distribution system from one or more main generating sources. It follows that, with the exception of the power supply itself, no element of the plant equipment is more vital or deserves more careful consideration than the primary distribution system with its switching and protective devices.

In steel mills having electric main roll drives the requirements of the distribution system are similar in many respects to those met with in central station practice, especially with regard to the amount of power to be handled and the high degree of reliability necessary. Since it is quite natural and proper to utilize as far as possible the methods of switching and protection adopted as a result of central station experience, consideration should be given to the similarities and differences in the general requirements of the two classes of service, in order that the experience in the one may be applied intelligently to the other. In both steel mill and city distribution reliability of service is of the highest importance. In both cases power is usually received from at least two principal sources, the area to be served is of such an extent as to require a number of distribution substations connected with the power sources by a loop or network, and the magnitude of the load will demand several circuits in parallel from power stations to substations. The points of dissimilarity exist principally in the nature of the load itself. The steel plant normally operates at full capacity continuously from the beginning to the end of the week thus taking a fairly constant average load throughout the 24 hours of each working day, in contrast with the widely varying day and night loads ordinarily encountered on city systems. Steel mill main roll drives, however, constitute large units of load which may be rapidly fluctuating, causing peaks and valleys of short duration in the plant load curve. Furthermore, the steel plant distribution system must supply a considerable proportion of its capacity through conversion apparatus to direct-current load which may also be subject to fluctuation. Aside from the character of the load another factor which directly affects switching equipment is that the average transmission distance in the steel plant is usually less than in city systems of corresponding capacity, the result being that the impedance of the distribution circuits is lower and the current which can flow into a short circuit at any point on the system will be greater.

The general conclusions which can be drawn from the consideration of these points of comparison are: that switching equipment used in steel plant service should be especially liberal in capacity since the "peak load" periods are six days long instead of a few hours, that devices used for protective service against line failures must be proof against operation under load fluctuations, but sensitive and rapid in case a fault develops, that particular consideration should be given to the question of short circuit values and the selection of apparatus suitable to meet them, and finally that switching equipment in common with most other steel plant apparatus offers the opportunity for inspection and overhauling every seven days even though it may be subjected to continuous heavy duty throughout a six-day week. The last consideration will often make advisable less duplication of apparatus and consequently greater simplicity than is common in central station practice, the tendency being toward fewer but heavier switches and simpler but more carefully safeguarded construction. From the economic standpoint the distribution system in central station work is one of the principal items in the cost of operation while the steel plant system is a tool which represents a comparatively small item in the cost of the finished product, but a tool which if seriously damaged may entail many times its cost in loss of production. Consequently there are few cases in steel mill service where the best in switching apparatus and construction is not justified even though a somewhat greater expenditure may be necessary.

The foundation for the design of a switching equipment is of course the connection scheme. While it is not the intention of the present discussion to consider the general layout of distribution circuits, it may be said that the usual substation or switching point will have two or more power supply circuits connecting it with the power stations or with other switching points, and also a certain number of feeders supplying the load in the vicinity. To meet such conditions a number of different switching schemes are available as indicated in Fig. 1. Although many further modifications are possible, the arrangements shown will serve for comparison. With the scheme shown in Fig. 1-A load is simply tapped off from either or both of two circuits which are controlled by switches in other stations. Simplicity and low cost are secured at some sacrifice in protecting continuity of service, although this sacrifice is not great if only one feeder circuit is to be taken off. The scheme in Fig. 1-B uses a single bus with one oil circuit breaker in each circuit and permits isolating automatically any circuit which develops a fault, without interrupting service on the others. In Fig. 1-C a second bus is added with selector disconnecting switches allowing access to either bus without dropping load. The load may also be carried in two groups if desired and may supply the circuits in each group separately. A double bus is also provided in the arrangement shown in Fig. 1-D but with two breakers per circuit so that any breaker may be isolated for inspection or repair at any time. Easy access to the oil circuit breakers is accomplished by Fig. 1-E with a smaller number of breakers and a single bus. Double blade disconnecting switches on the feeders are used to connect two or more circuits to one breaker for temporary operation, thus allowing any breaker to be taken out of service without interrupting the load.

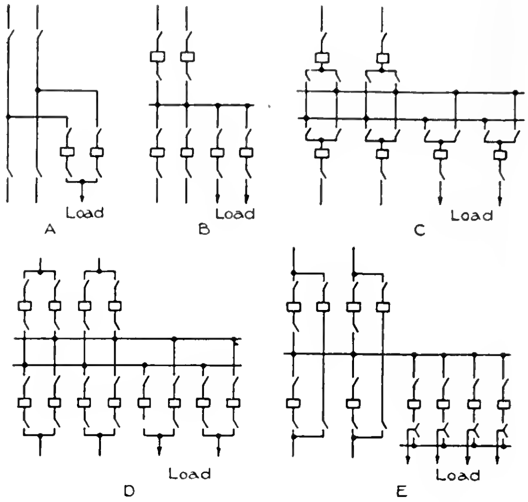

Fig. 1. Connection Diagram Illustrating Various Switching Arrangements

The selection of a connection scheme must of necessity depend on the particular conditions involved, and it is possible to point out only a few general considerations. Simplicity is an important factor in any installation and particularly in steel mill work on account of the reduced possibility of confusion in operating and because more careful maintenance can usually be secured where a smaller amount of equipment is involved. From the standpoint of simplicity alone we might use the arrangement shown in Fig. 1-B, but the element of flexibility must also be taken into account to determine whether or not the conditions justify a more elaborate scheme. Flexibility as provided by double buses, duplicate oil switches, and various other expedients serves two main purposes; to meet the requirements of changing load conditions and to allow access to parts of the equipment at all times for maintenance purposes and for making extensions. These features are often of great value, but in a great many cases they will prove to be of less importance in the steel mill system than in the city distribution system because there is less change in the load conditions, less necessity of changes and extensions in the equipment, and because the weekly light load period can be more easily taken advantage of. Reliability of relay protective schemes can be more easily secured with single bus arrangements and simple connections. Consequently the more elaborate connection schemes should be adopted only when circumstances definitely demand their use and when proper consideration has been given to the disadvantages as well as the advantages involved.

The oil circuit breakers constitute the most important item of the station control equipment and the reliability of the plant power is greatly dependent on their successful operation. They must be capable of interrupting the maximum amount of short circuit current which can be fed into the circuits which they protect and to this end it is highly important that a careful survey of the distribution system be made to determine the value of this maximum current. Liberal allowance should be made for further growth in the quantity of synchronous apparatus connected to the system and in the number and size of circuits required to carry the load. The methods of calculating short circuit current after having determined the future system characteristics are well known. On loop systems or networks frequently used in steel mill practice the calculating table is of great assistance in simplifying the calculations.

The interrupting capacity requirements of a large plant usually demand breakers of a heavy type which for ease and certainty of operation should be electrically rather than manually controlled, and consequently a thoroughly reliable direct current supply, preferably at 125 volts, is required for oil circuit breaker operation. A storage battery is by far the most satisfactory method of obtaining such a supply and the advantages of its use to obtain reliability fully justify the cost and the small amount of maintenance required.

In steel mill service the manner in which switching apparatus is installed is especially important. The possibility of insulator flashovers and the breakdown of insulation is greater than in most other classes of service due to accumulation of conducting dust and presence of moisture and corrosive gases. To prevent arcs which form in this manner from communicating to other apparatus and causing serious damage is one of the principal considerations in the design of the switching structure. Another is to protect operators and others as far as possible from accidental contact with live parts. To design for these results it is first necessary to have sufficient space so that the structure may be designed with proper clearances. Too often the switching apparatus is made to occupy the space which is left when everything else has been provided for, the result being a switch room which is a menace to the power supply as well as to persons who enter it. The second requisite is to protect the live parts of the equipment, either by enclosing in compartments or by suitable insulation, so that the conducting gases produced by an arc will be prevented from causing additional breakdowns. Experience has proved beyond question the effectiveness of masonry cells and barriers in preventing the spread of arcs, and if the switch and bus compartments are equipped with doors which serve to enclose live parts completely greater safety from accidental contact is secured as well as greater probability of confining trouble to one point in the structure. Even though the doors may be blown off the compartment where the trouble starts it is unlikely that the doors of other compartments will be disturbed. In general the use of cell and compartment construction will be fully justified for any important switching equipment in steel mill service.

The actual design of switch structures involves an almost infinite variation in detail depending on the type of breakers used, the manner in which the various circuits are to enter and leave the building, the character of the building construction and the space available, and many other factors. It is, therefore, difficult to prescribe a definite structure design which will fit more than a small percentage of cases and any appreciable amount of standardization appears to be impossible. It is obviously desirable, however, and often possible to standardize to some extent the various structures, installed in one plant, and in selecting a design for a particular location it is well to consider the feasibility for using the same general scheme for future work at other probable switching points. However, the best procedure is to work out the arrangement for each substation based on the conditions existing, and to obtain such uniformity as is possible without sacrifice of safety or reliability. The following are some of the points which it is well to bear in mind in designing the structure.

Each phase should be in a separate compartment, where it is necessary to have copper exposed as, for example, in the case of disconnecting switches. Busses and connections, if completely insulated and protected from mechanical injury, may be run on post insulators with all phases in one compartment or entirely in the open and still provide a very safe construction.

Connections should be as direct as possible and should be adequately supported against magnetic stresses resulting from short circuit. Loops which tend to increase the short circuit stresses should be avoided. Connections may be run in walls or floors by use of fiber ducts imbedded in the concrete and properly insulated cable. This often proves a very useful expedient and at the same time gives good protection to the leads.

Oil circuit breakers, disconnecting switches, current transformers and insulators should be so placed that they are readily accessible for inspection as well as quick repair or replacement. A device in an awkward location seldom receives proper attention and causes loss of time if replacement becomes necessary. Deep and narrow compartments are undesirable for this reason.

The possibility of opening disconnecting switches by mistake on circuits carrying load is always a serious danger to operators. A liberal operating aisle may prove a worth while investment if an accident of this sort occurs and in addition the structure can often be arranged to minimize the chances of confusing one circuit with another.

If the switching equipment is to perform efficiently its function of safeguarding the power service it must have as an auxiliary a carefully applied and well maintained protective relay equipment. For the best protection the relays must so function as to trip those breakers and only those necessary to isolate a faulty circuit from the rest of the system. Also, the fault must be cleared with minimum delay to lessen the disturbance to the rest of the system and the possibility of synchronous machines falling out of step. On individual feeder circuits the requirements are met by ordinary over-current relays having adjustable time delay which may be set to prevent tripping under normal load fluctuations. For power supply circuits between stations it is usually necessary to trip the breaker at each end of the faulty line in order to clear the trouble. In most cases two or more circuits are operated in parallel making it possible to use balanced current or balanced power relays which depend for their operation on a difference or reversal of power flow over one circuit of the paralleled group. They are, therefore, practically unaffected by overload or short circuit disturbances except on that particular circuit where the trouble exists. The circuit in trouble, however, is tripped out with minimum delay since it is not necessary to depend on long time settings to secure the desired selective action. Reliable relay schemes and devices are available to meet practically every protective requirement and their proper application is a matter of vital importance in steel mill service.

Finally, it is impossible to over-emphasize the value of good appearance. The quality of service secured from electrical as well as other types of equipment is, in the final analysis, greatly dependent on the human element. Switching apparatus installed in a well lighted room, protected from mill dirt, and constructed with the best grade of workmanship, immediately becomes a matter of pride to the individuals responsible for its operation, and the careful attention to details which constitutes good maintenance is difficult to secure unless such an attitude of mind exists.

Adjustable Speed Main Roll Drives

By A. K. Bushman

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There are various methods of obtaining the adjustable speed control of the main rolls used in the manufacture of steel. The author considers the advantages and disadvantages of each, first dealing with the direct-current methods available, including motor field control, Ward Leonard control and a combination Ward Leonard and motor field control. After some general comments covering direct-current methods as a whole he passes on to consider and discuss the pros and cons of the alternating-current systems which are available and includes under this heading the Kraemer system, Scherbius system and a polyphase brush-shifting, alternating-current motor with shunt characteristics. His contribution is concluded with some general remarks comparing the relative merits of the alternating-current and direct-current systems.—Editor.

Perhaps no questions in regard to main roll drives in steel mills cause more perplexity than those which arise due to the need for adjustable speed. The object of this article is to present the advantages and the disadvantages of the various types of adjustable speed equipment as they are considered by the electrical manufacturer when preparing recommendations for a proposed installation.

In every case the drive must be fitted to the load, therefore, the first duty of the engineer is to analyze the working conditions carefully and to determine the power required at the different speeds. These are then plotted as points on cross section paper, horse power against speed, and the motor rating must be sufficient to include every point. This rating, due to the inherent characteristics of electric motors which usually fall under one of the three classes, will be constant torque, constant horse power, or a combination of the two. Constant torque is represented by a straight line drawn from the origin (zero speed and zero horse power) at any angle to the axis. Constant horse power of course, is a straight line drawn parallel to the speed axis.

Fig. 1 is typical of the third class. In this case the proposed operating schedule requires constant torque from 220 to 550 r.p.m. and constant horse power from 550 to 750 r.p.m. The low speed of 220 r.p.m. in this particular case is necessary for mill adjustment and is not required for actual production. If the points above 550 r.p.m. were not required the motor could be rated at constant torque up to 410 r.p.m. and at constant horse power from 410 to 550 r.p.m.

The principal types of adjustable speed drive available are: direct current with motor field control; direct current with generator field control (Ward Leonard); a combination of motor field control and Ward Leonard control; Kraemer system; Scherbius system, which is built for operation below synchronism only (single range), or for operation both above and below synchronism (double range). For smaller drives there is also available a three-phase brush shifting motor with shunt characteristics, that is, the motor speed remains practically constant regardless of load. The equipments as applied to main roll drive will be considered in the order given.

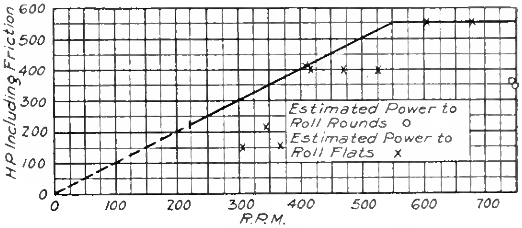

Fig. 1. Curve Showing Estimated Power to Roll Round and Flat Bars. Motor Rating 220/550/550 h.p., 220/550/750 r.p.m.

Direct Current—Motor Field Control

This consists of a direct-current motor, usually shunt wound, running from a constant potential bus, suitable equipment being provided for starting the motor. Speed adjustment is obtained by means of a rheostat in the motor field. This was the first adjustable speed electric drive devised and for years was the only recourse where constant speed was not satisfactory. It is still highly favored on account of its simplicity and has been used in several notable installations, such as individual drive of stands of a continuous strip mill, etc., on account of its adaptability to special control systems. The motor is inherently constant horse power over its speed range and if constant torque is required the motor is oversize at its low speed by approximately the ratio of maximum to minimum speed.

In cost this motor with its control is cheaper than any other adjustable speed drive but, except in the rare cases where direct current is available without conversion from alternating current, the cost of its proportion of the motor-generator or synchronous converter and transformer equipment must also be charged against the drive. This charge will often make some other equipment competitive on a cost basis.

The efficiency of the installation is low. To be sure, the motor may be guaranteed 92 per cent or better at full load but the efficiency of the conversion equipment will not average better than 90 per cent. Then, too, it is usual to use a 230-volt motor with a 250-volt generator to allow for bus drop, thus the transmission efficiency is 92 per cent. Multiplying the above assumed values, the overall efficiency is 76 per cent. Under ideal conditions this may be bettered by several per cent, but an average installation will not be far from this figure.

Another disadvantage of obtaining adjustable speed by motor field control is that it necessitates an uneconomical use of material at the higher speeds. For example, assume a motor rated 1500 h.p., 200/400 r.p.m., 600 volts. This motor will have to be somewhat more liberally designed than a 1500-h.p., 200-r.p.m., 600-volt machine in order to insure stability and good commutation at 400 r.p.m. From this same mass of material a 3000-h.p., 400-r.p.m. motor could be built, but it is impossible to rate this machine 1500/3000 h.p., 200/400 r.p.m. at constant voltage.

No definite figures can be given in regard to speed range obtainable by this method since the maximum speed is limited principally by commutation and stability. By using a liberal design, compensating windings, etc., successful motors have been built with a speed ratio as high as 5 or 6 to 1, but in large sizes the range is usually kept below 3 to 1, and 2 to 1 is a common figure.

Direct Current—Ward Leonard Control

This equipment consists of a direct-current motor, usually shunt wound, receiving its power from a generator which is also usually shunt wound. The motor operates with its field excited at a constant value and its speed and direction of rotation are controlled by the strength and polarity of the generator field. Evidently the motor is inherently constant torque and, therefore, the material of which it is built is used economically. For example, the rating of a motor of the same physical size as that considered under the heading of Motor Field Control would be 1500/3000 h.p., 200/400 r.p.m., 300/600 volts. In this case, however, the power set is working at full capacity only when the motor is running at top speed which may be but a small part of the time.

Since the motor output and also its voltage are proportional to its speed it is evident that the motor requires the same current for rated load at any speed and, therefore, the overall efficiency is very low at the low speeds, but is good at high speeds. Assume for example,

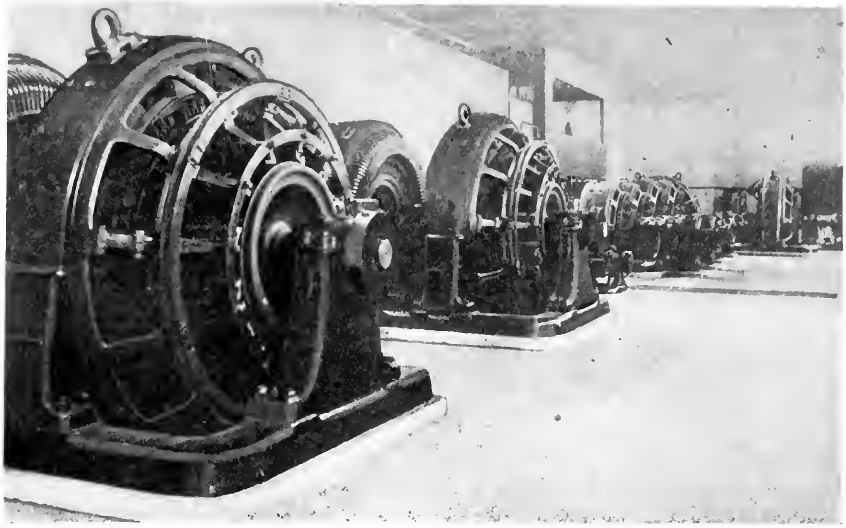

Fig. 2. Motor Room of the 14-inch Hot Strip Mill, Trumbull Steel Company, Containing Two 2300-kw., 600-volt, Direct-current Generators Direct Connected to 2300-volt, Synchronous Motors, 150-kw. Exciter, Four 800-h.p., and Two 1250-h.p. Direct-current Motors

the same efficiencies as in the previous example. At 400 r.p.m. the motor efficiency is 92 per cent and the set efficiency is 90 per cent, the bus loss should be small, say 2 per cent, for the motor and its generator will probably be placed near together. The overall efficiency is therefore 81 per cent. At 200 r.p.m. the I^2R losses are the same as for 3000 h.p. but are twice the percentage of the motor output which is only 1500 h.p. at this speed. The motor field loss is also the same, the machine driving the generator is running at half load and hence at reduced efficiency and only the motor core loss and friction and the generator core and field losses are reduced in proportion to the load. The efficiencies of this equipment would probably be about as follows: motor 86 per cent, set 85 per cent, transmission 96 per cent, overall just over 70 per cent. At lower speeds the overall efficiency is correspondingly decreased. Obviously this type of drive is entirely unsuited for a constant horse power equipment since neither the main motor nor the generator would ever be used efficiently.

Ward Leonard drives have many advantages to offset their poor efficiency at low speeds. The control is extremely simple and reliable. There is no limit to the speed range for by using forced ventilation of the main motor the speed may be reduced to zero with no diminution of torque. Also, weakening the generator field to reduce the speed causes the motor to regenerate and not only gives a most effective brake for a quick stop, but the stored energy in the motor armature is returned to the line instead of being wasted. When starting, no series resistance is used and the power drawn from the line is only that necessary to accelerate the armature instead of about double this amount as is required when starting from a constant potential bus. When the motor is started and stopped very frequently as on reversing mill drives, this saving of power on each start and stop is a very important item.

In large sizes Ward Leonard equipments are little if any more expensive than a constant speed direct-current motor of the same maximum horse power and speed with control and switchboard and its proportionate share of the direct-current generating equipment, etc. In small sizes, however, the Ward Leonard drive becomes much more expensive on account of the higher cost of several small generators than one large one, also, the separate exciter required for voltage control is a larger percentage of the whole drive.

Direct Current—Combination Ward Leonard and Motor Field Control

Many mills require a combination of constant torque and constant horse power. In these cases, Ward Leonard control is used over the constant torque part of the range and motor field control is used for the upper part of the speed range. The high torque passes must be rolled with full field on the motor in order to keep the size and cost of the equipment at a minimum, since the current required to give a certain motor torque is inversely proportional to the strength of the motor field, or, in other words, the torque per ampere of a two to one speed motor by field control is half as much at top speed as at full field speed. Using a combination of voltage control and motor field control, where the horse power required at various speeds will allow it, effects a marked saving in generator cost over using voltage control for the whole speed range and a large saving in motor cost over using field control alone. Naturally the combination retains the advantages and disadvantages of both components.

General Comment on Direct-current Adjustable Speed Drives

Direct-current equipment of the types under consideration possess a great advantage over their alternating-current competitors in that they are well known, had been used successfully for years before alternating-current adjustable speed drives were invented and every one who has had any electrical experience feels that he understands them thoroughly. This feeling in some cases may or may not be justified but it is of great importance nevertheless. Other things being equal or nearly so, the engineer of limited experience will usually prefer direct current.

On the other hand, direct current has two great disadvantages. First, in the great majority of cases it is much less efficient than a corresponding alternating-current drive, due to the losses which are incurred when converting alternating current to direct current; second, it has to carry all its power on two commutators and it is well known that a commutator is always a potential source of trouble. It must be kept clean and free from oil. It must be kept smooth and free from ridges. The brushes must move freely in their boxes and the spring pressure be kept at the proper value. In spite of all care, a short circuit on the bus or a heavy overload or some object dropped on the commutator causes a flash over with the usual results of roughened surface, burned brush rigging, etc., often necessitating a shutdown to grind and slot the commutator. These two disadvantages of direct-current drives were the cause of a persistent effort to develop an alternating-current adjustable speed drive and so far two successful systems have been developed. While neither system eliminates commutators entirely their size and the power they handle has been greatly reduced and in most cases a large increase in efficiency has been secured.

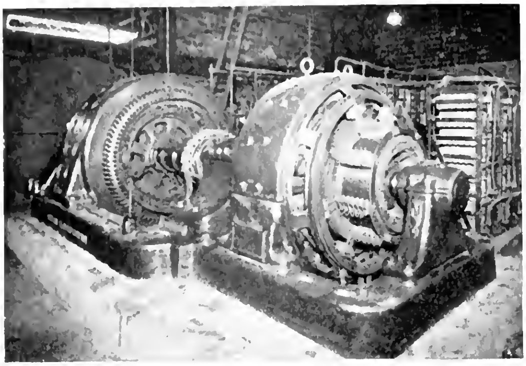

Fig. 3. Steel Mill Induction Motor Kraemer Single Range Control, Rated 1400/1400 h.p., 600/405 r.p.m.

Kraemer System

This well known system consists of a synchronous converter running from the slip rings of the main induction motor and delivering direct current to a motor direct connected to the main motor shaft. This apparatus can regulate only below the synchronous speed of the induction motor but its range is unlimited except by economic considerations.

The drive utilizes equipment which is used for other purposes and with which every engineer is acquainted. It should be noted, however, that these familiar machines are used in an entirely new way which introduces difficulties not encountered in their ordinary operation. For example, the direct-current motor direct connected to the main induction motor is operated at maximum speed at minimum voltage and minimum field, and when running at lowest speed it has to generate its highest voltage. The speed of the direct-current motor is fixed by the induction motor and not by the direct-current voltage and motor field except as these factors affect the induction motor. It is evident, therefore, that the direct-current motor is in no sense a "standard" motor.

The synchronous converter also operates peculiarly for its speed is constantly changing, whereas the converter, as commonly known, runs at constant speed. This changing speed of the converter is the weak point of the system for a converter has low synchronizing torque—its torque being merely sufficient to supply friction and windage losses which, of course, are constant at constant speed. Assume, for example, a Kraemer set running light at 5 per cent below synchronism. The slip of the set from no-load to full-load will be approximately 5 per cent, therefore when the load is suddenly thrown on the main motor the frequency on the synchronous converter is doubled and the converter speed must be doubled. If the frequency increases too fast the converter will fall out of step and stop, leaving the main motor running non-regulating and the converter standing still with alternating current impressed on the slip rings from the induction motor secondary, with direct current impressed on its commutator from the direct-current motor and with very heavy currents circulating. To insure against this it is often necessary to install a flywheel on the mill solely to reduce the rate of change of load so that the converter will have time to change its speed without exceeding its synchronizing torque. The cost of the flywheel under these conditions must, of course, be charged against the Kraemer equipment, as must also the power required to drive the wheel, since the flywheel would not be necessary with another type of adjustable speed drive.

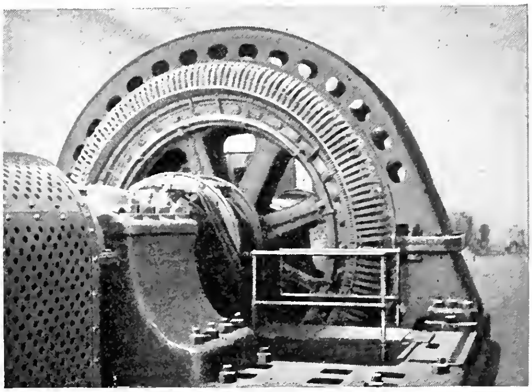

Fig. 4. Steel Mill Induction Motor Rated 5500/4400/3400 h.p., 170/136/105 r.p.m., 6600-volt, Scherbius Double Range Speed Control Driving the 20-inch Hot Strip Mill at the Gary Plant of the Illinois Steel Co.

Another disadvantage of the converter is that it will not run at very low frequencies and hence there is a gap in the speed range between the non-regulating speed and the highest regulating speed. For the same reason the converter cannot be used to give power-factor correction when operating near synchronism. Also, there must be supplied a source of direct current to excite the field of the direct-current motor and of the synchronous converter; thus, continuous operation depends upon the continuity of both an alternating-current and a direct-current system.

This drive having the direct-current motor direct connected to the main motor requires much more room at the mill than would be necessary for the induction motor alone and in case of trouble with the direct-current motor repairs cannot be made while operating non-regulating unless the machines are uncoupled.

The Kraemer system has many advantages, and many successful installations testify to its practicability. In common with all the systems described it has its own field in which it is pre-eminent. Its overall efficiency is better than that of direct current and the size of the commutators required are greatly reduced since only the slip energy is carried on two commutators instead of all the energy as is the case with direct current. In addition there is the commutator of the exciter which is of small capacity compared to the main motor.

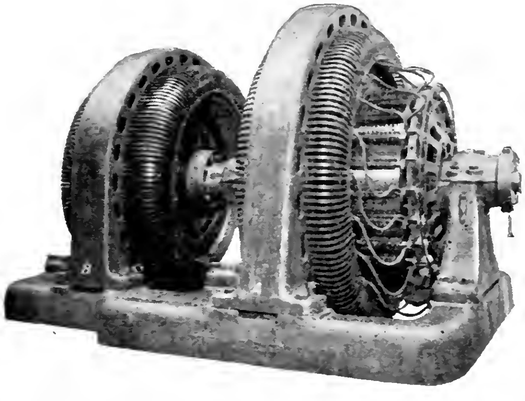

Fig. 5. Scherbius Double Range Speed Regulating Set for use with the 5500 h.p. Motor shown in Fig. 4

This system is especially suited for drives having large speed ranges when the main motor speed is such as to give an economical design for the direct connected direct-current motor and when constant horse power is required throughout the speed range. Under these conditions the Kraemer drive will prove cheapest in first cost. It should be noted, however, that in case of trouble with the regulating equipment so that the main motor has to be operated non-regulating, the speed will be the maximum of which the drive is capable, and, therefore, only a small per cent of the usual sizes of product can be rolled.

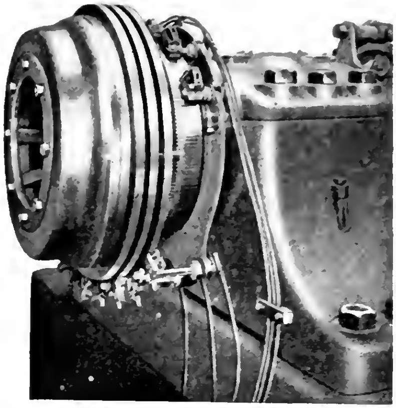

Fig. 6. Ohmic Drop Exciter 1.6-kv-a. Mounted on Shaft of 600/600/600 h.p., 469 375/281 r.p.m., Steel Mill Induction Motor. Scherbius Double Range Control

Scherbius System

Although a more recent development than the Kraemer there are more installations of this system in the United States than all other adjustable speed alternating-current drives combined, not including small brush shifting alternating-current motors. The apparatus consists of a main induction motor and a regulating set which in turn is composed of a perfectly standard type induction motor direct connected to a three-phase commutator type regulating machine. The double range system also includes a small machine known as an ohmic drop exciter direct connected to the main motor.

This system labors under two disadvantages: First, the speed range is limited by the fact that it is undesirable from a design standpoint to handle more than 15 to 18 cycles on the regulating machine. This means that on a 60-cycle equipment the range is limited to approximately 70 per cent synchronous speed as a minimum and 130 per cent as a maximum which gives a speed ratio slightly less than 2 to 1. On 25 cycles a 3 to 1 range is easily obtained. Secondly, engineers who have not had experience with the Scherbius drive feel that it is complicated and involves machines with which they are totally unfamiliar. It cannot be denied that the vector diagrams and design calculations are highly complicated, but the operator is no more concerned with these than with similar and equally complicated calculations involved in the design of an ordinary induction motor. In both cases the results of these calculations are built into thoroughly reliable machines which require only simple and easily understood adjustments and care. The fundamental principles involved are the same as for the Kraemer system and the machines themselves are as easily understood.

The regulating machine is exactly like a modern direct-current generator except it is wound for three phases instead of one. In fact a one line diagram of the two machines is identical. Both are driven at practically constant speed and both generate a voltage which is a function of the shunt field strength. Both have an interpole field and a compensating (pole face) winding to insure good commutation at all loads. The only point of difference is that the direct-current generator is excited with direct current and the regulating machine is excited with alternating current from the main induction motor secondary, and, therefore, generates alternating current of the same frequency as its excitation. In experimental work a direct-current generator coming through the factory in regular production, by making a few changes, has been used to regulate the speed of an induction motor. The generator was later changed back to a straight direct-current machine.

The small ohmic drop exciter is nothing more or less than the armature of a synchronous converter with a ring of sheet iron punchings without windings replacing the usual stationary field. This little machine is pressed on the main motor shaft and receives line frequency on its rings through a potential transformer and so gives slip frequency on its commutator. The only other apparatus involved is a contactor panel and two or three transformers which are used in place of rheostats since all circuits are alternating current.

The Scherbius drive reduces the number and size of the necessary commutators to a minimum since the slip energy is handled on but one commutator as against two in the Kraemer. It should, also, be noted that for similar speed ranges the slip energy is much less for double range apparatus than for the Kraemer. For example, in an equipment giving a speed ratio of 1.67 to 1 the slip energy of the Scherbius drive at maximum regulation is 25 per cent of the primary power while it is 40 per cent under the same conditions with the Kraemer. The commutator of the ohmic drop exciter is smaller than that of the exciter required for the other system and in addition is for very much lower voltage—usually about 20 volts.

Operation both above and below synchronism is an extremely valuable feature which can be obtained with good commutation on the auxiliary machine only in the Scherbius system. Double range operation not only greatly reduces the capacity of the regulating apparatus for a given speed range, but in case it is desirable or necessary to run non-regulating, the motor speed is about midway of the range and therefore practically all regular sizes and shapes of product can be rolled. Also, the maximum efficiency is obtained at this average speed at which the mill operates a large part of the time, instead of at maximum speed as in all single range equipments.

There are no synchronous machines in this drive and, therefore, no danger of any part of the apparatus falling out of step. Also, no direct current is required for excitation or any other purpose and so there is no dependence on any source of power other than the main alternating-current line. There are no gaps in the speed range, any speed from maximum to minimum being obtained by operation of a single control handle, and there is no diminution of overload capacity at any point in the range. When running at synchronous speed the regulating equipment may be used to maintain high power-factor which is very desirable when the power contract carries a clause penalizing low power-factor. The system may be built for constant torque, constant horse power or constant torque below synchronism and constant horse power above, thus it is suitable for practically any combination of speeds and horse power which may be required.

From the foregoing brief outline of Scherbius characteristics the reasons for its use in the majority of adjustable speed alternating-current installations will be evident. The exceptionally large number of repeat orders are evidence of its reliability.

Polyphase Brush Shifting Alternating-current Motor with Shunt Characteristics

This motor involves the same principles as the Scherbius double range system but in small sizes it is possible to eliminate the regulating set, contactor panel, transformers, etc., and obtain complete control by means of two sets of brushes whose relative position on the commutator is altered by means of a hand or motor operated brush shifting mechanism. This motor has characteristics practically identical with the double range Scherbius equipment and fills a long felt want for an adjustable speed alternating-current drive where the power required is too small to make Scherbius or Kraemer apparatus feasible on account of the high initial cost of very small installations.

The output of this machine is limited to a certain maximum per pole and it is, therefore, necessary to use low speeds to obtain high ratings. Motors are now being built from 25 h.p. up to 600 h.p. with speed ranges up to 3 to 1.

Alternating Current *vs.* Direct Current

There has been a great deal of discussion of the relative merits of alternating-current and direct-current drive and each has its ardent supporters. Similarly Kraemer *vs.* Scherbius has been argued pro and con. A broad view of the subject, however, will show that such systems cannot be compared except in relation to a particular set of conditions, therefore, which system is preferable must be determined for each proposed installation and, unfortunately perhaps, cannot be settled once for all. The electrical manufacturer who builds all types chooses the drive for the mill in question just as a workman chooses the proper tool for the work in hand from a well fitted bench. It is only when a complete line is not available from which to choose that it is necessary to try to compare adjustable speed drives as such.

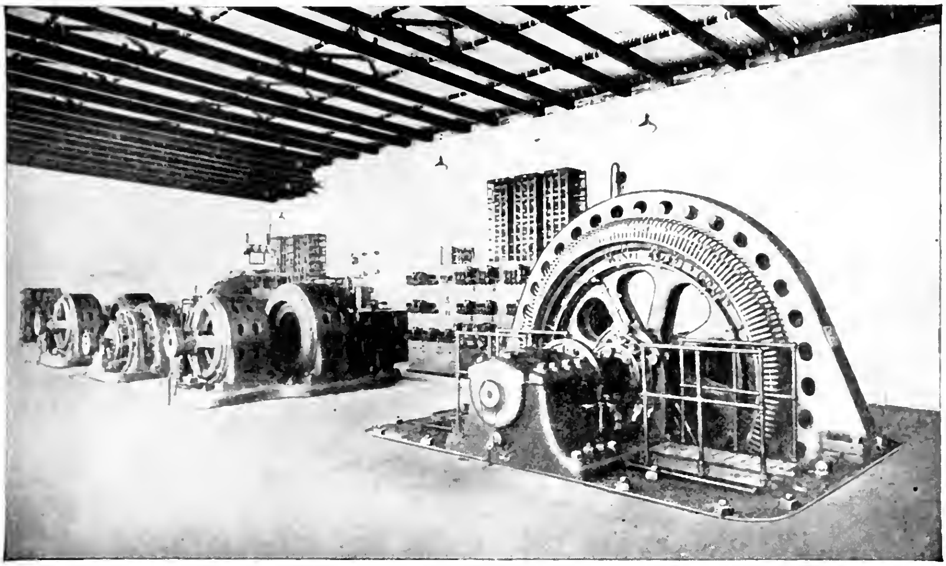

Fig. 7. Scherbius Speed Regulating Sets and Adjustable Speed Induction Motors for Hoop Mill Drive. Finishing Mill Motor in Foreground Rated 1800/1500/1200 h.p., 240/200/160 r.p.m., 2300-volt, 3-phase, 60 cycles

Since alternating-current systems were developed to overcome certain universally recognized defects in direct-current apparatus, it is safe to say that in general alternating current is preferable to direct current if equal results can be obtained. Past this point generalization is dangerous in the extreme. As an example, it may be interesting to note that the same manufacturer recently sold two 4500-h.p. mill motors; one was the largest single unit direct-current motor ever built in the United States and the other was the largest Kraemer drive. Such apparently contradictory recommendations are but the natural result of fitting the drive to the mill conditions.

Flywheels for Steel Mill Drives

By L. A. Umansky

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The author has written a very complete treatise on the use of flywheels for steel mill drives. He takes into consideration the character of the rolling mill load; the energy of flywheels; characteristics of induction motors; the influence on duty cycle; the effect on motor size; cost of operating flywheels; their application and misapplication and steam and electric drives. After covering this part of the subject very completely, under the heading of "Flywheel Calculations," by the aid of numerous but simple formulae and examples he shows how to calculate the total stored energy; the energy available for regulation, and the acceleration and retardation of flywheels. He then shows numerous means of varying the secondary resistance; discusses direct-current drives, and concludes his contribution with some remarks on the mechanical arrangement.—Editor.

Introduction

Flywheels have been known to engineers much longer than electric motors; but the combination of these two devices is hardly twenty years old. Although the fundamental theory of this combination was developed at once, there still exist today many conflicting views and confused ideas about the use of flywheels for electric drives—even among those that are using them.

For instance, one steel mill superintendent, brought up in the steam engine days, insists on having all his electric drives equipped with flywheels "In order to reduce the variations of speed with the load;" on the other hand, it is well known that if we have two electrically-driven mills, both equally well designed, but one for flywheel operation and the other for operation without, the former drive should show a greater speed variation than the latter.

The problem before us lies on the borderline between mechanical and electrical engineering, touching both sides. This possibly explains why many practical engineers of either profession are sometimes reluctant to look up their old handbooks, flavoring of mathematics, and prefer to be guided by the "Rule of Thumb."

This fact serves as the excuse for writing this article. Nothing basically new is told in it, but a few old established facts are looked into from a possibly different angle. An attempt is made to consider the problem not merely in a formal way but rather from the standpoint of common sense. Mathematics are not excluded from the discussion, because this science is but systematized common sense; but whenever applied, it is intended as a supplement to the plain reasoning, and not as a means to conceal the lack of physical conception.

GENERAL CONSIDERATION

Character of Rolling Mill Load

Fig. 1 shows schematically an induction-motor driving a three-high (i.e., non-reversing) mill; it may be, for instance, a plate mill drive, like the one illustrated in Fig. 2. A slab will be passed between the lower and the middle rolls, and then passed backward between the two upper ones. A number of such passes will be required before the slab is rolled down to a thin plate.

When the metal is in the rolls it is being deformed and elongated and the power required to accomplish this is quite large. During the intervals of time when the slab is being transferred from the two lower rolls to the two upper ones, and vice versa, there is no load on the mill except the comparatively small friction load.

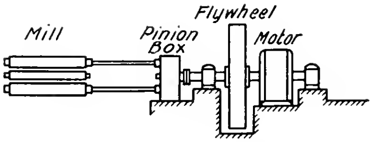

Fig. 1. Layout of a Three-high Non-reversing Rolling Mill Driven by an Induction Motor Equipped with a Flywheel

Fig. 3 shows a load diagram for a large plate mill. This load, or duty cycle, is none too good for any kind of drive; the load peaks are of a "violent" character, high in value and of short duration. But such is the nature of the rolling work, over which we have but little control; if for instance, the rolling schedule should be maintained and the mill requires 13,300 h.p. during the first pass, this amount of power should be delivered to the rolls, otherwise the metal will not be put through the mill.

Now, all plate mills are equipped with flywheels. It is admitted that they help the motor considerably in carrying the high peak loads; numerous tests have proven this point. But how is this help extended? How is it that this great rotating mass reduces the amount of power that the motor draws from the line?

Flywheel Energy

Any rotating mass, or more generally, any moving body possesses a certain amount of energy. It requires an outside effort to bring it up to speed, but once this is done, the energy that was spent for doing it is not lost; it is "stored" in the rotating flywheel, ready to be liberated and used at will. A wheel of given dimensions and weight possesses a strictly definite amount of such stored energy at any definite speed; this amount is proportional to the square of the speed and we shall show later how to calculate it. But first of all we must understand how to use up, if necessary, a part of that stored energy.

There is but one way of doing it: to let the flywheel slow down. When its speed is reduced, the amount of stored energy is manifestly less; but where is the balance? It was given out as mechanical work at the shaft; in our case it did part of the work of deforming the metal, and the electrical motor made up only the balance of the total work required for the rolling during the pass.

Without allowing the flywheel to slow down its stored energy is of no use for our purpose. Imagine the mill being driven by a sufficiently large synchronous motor. This machine will run at strictly constant speed or will not run at all; and the power input to such a drive will be the same regardless of whether the drive is, or is not, equipped with a flywheel.

Induction Motors

But our plate mill is driven by an induction motor. We know the inherent characteristic of this machine: the greater the load imposed the more is the drop in speed, or "slip." Expressed in per cent of the no-load speed (practically the same as the synchronous speed) the slip may be assumed proportional to the load, other conditions being equal. Thus if a 1000-h.p. 600-r.p.m. (synch.) induction motor runs with a slip of 3 per cent, i.e., at 582 r.p.m. at full load, it will have a slip of only 1.5 per cent (591 r.p m.) at 500-h.p. load, and so on.

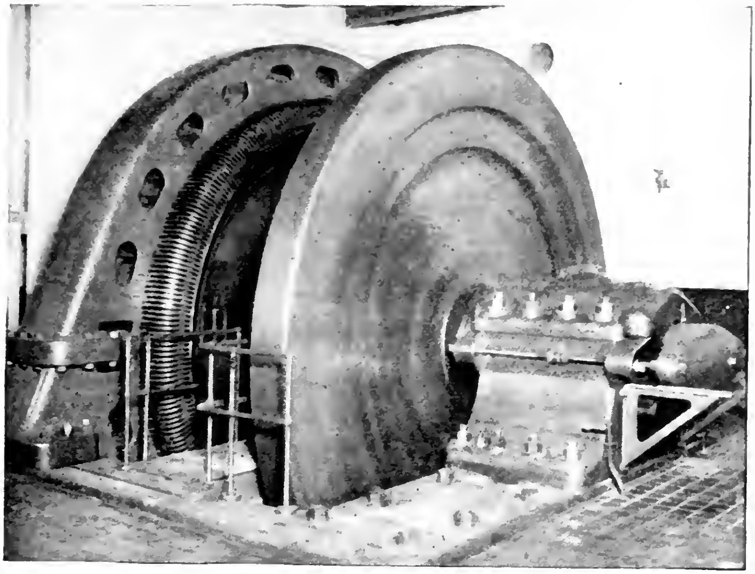

Fig. 2. 4000-h.p., 83-r.p.m., 6600-volt Induction Motor Driving a 110-in. Plate Mill

There is another way of looking at this fact: when an induction motor with a fixed permanent resistance runs with a certain slip, it carries but one, and only this one, definite load. "Tell us the slip and you thus tell the load."

Another factor affecting the slip is the amount of resistance in the rotor circuit. We express it in per cent and say: the motor has 3, or 5, or 10 per cent secondary resistance.

The meaning of this is: the resistance is such that the motor runs at *its full load* with 3, or 5, or 10 per cent slip. For instance, the 1000-h.p. motor referred to above had a 3 per cent secondary resistance. Assume that we double the amount of the secondary resistance; the full load slip will be 6 per cent and we shall have a 6 per cent resistance.*

We must keep these basic facts in mind while discussing the use of flywheels in conjunction with induction motors.

Influence on Duty Cycle

Let us select, for instance, pass No. 4, of that duty cycle which is represented by Fig. 3, and see more closely (on Fig. 4) what will take place during that period.

The mill is driven by a 3500-h.p. motor with 5 per cent resistance. Just before the metal entered the rolls, the motor was running light overcoming only the mill friction of 300 h.p.; the corresponding slip is therefore $5\times\frac{300}{3500}=0.43$ per cent. As soon as the rolling begins the load imposed on the mill rises instantly to 7200 h.p.; but the motor cannot assume this whole load, until its slip reaches the value of $5\times\frac{7200}{3500}=10.3$ per cent—a long way off the 0.43 per cent that existed at the beginning of the pass. For that reason the load is at first carried almost entirely by the flywheel, which of course slows down inasmuch as it gives out its stored energy. But the more the flywheel and the motor connected to it slow down, the larger becomes the motor slip and proportionally larger becomes the motor's share of the total load. The flywheel's share, on the other hand, becomes smaller and smaller, and therefore the wheel does not have then to slow down at the same rate as it did in the beginning.

This performance is well illustrated in Fig. 4: the gradually increasing motor output is shown by the curve AB; the area under it ($OABF$) gives the amount of work (in h.p.-sec.) done by the motor during that pass. The shaded area $ACDB$ stands for the energy given out (in h.p.-sec.) by the flywheel. The motor slip is illustrated by the curve $A'B'$ in the lower part of the diagram; this curve is proportional to the motor load curve AB.

At the end of the pass under consideration (which lasted for 0.95 seconds) the motor output increased from the original 300 h.p. to 4500 h.p., and the slip from 0.43 per cent to 6.43 per cent. After the metal leaves the rolls at the end of the pass the remaining external load amounts to only 300 h.p. (friction) whereas the motor slip at that instant is such that the motor develops 4500 h.p. This excess capacity developed by the motor causes the flywheel to accelerate. The fact that the drive speeds up makes the motor slip smaller and smaller (see line $B'E'$) and therefore the motor output decreases in the course of time (see line $B\ E$). At the end of the interval between the passes the drive may have regained practically the initial speed, corresponding to 300 h.p. friction load. During this second period the motor obviously develops more power than is necessary to carry the small friction load; the excess of work done by the motor is used to speed up the flywheel, i.e., this work tends to replenish the stored energy partly spent during the previous pass. This is represented by the shaded area $B\ E\ F$ in Fig. 4.

Fig. 3 and also Fig. 4 illustrate very convincingly the effect produced by the flywheel

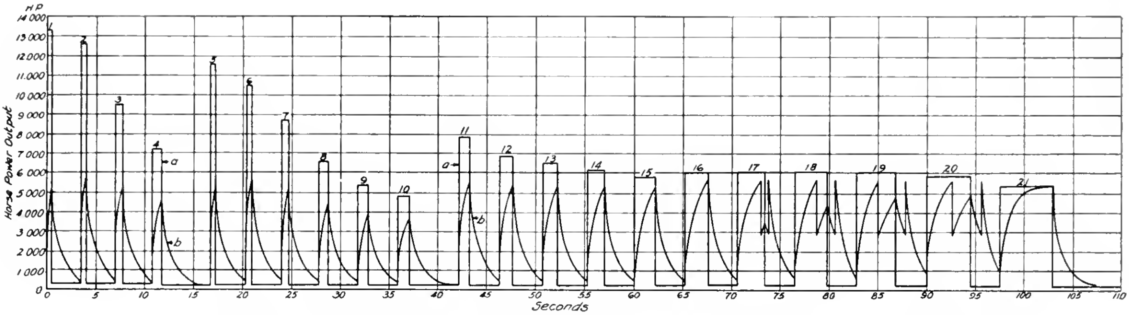

Fig. 3. Calculated Duty Cycle of a Large Plate Mill. Curve (a) shows the total power required for rolling; Curve (b) indicates the motor output if assisted by a large flywheel

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* Induction motors of the sizes used for steel mill drives have a normal slip of 1 to 2 per cent; when larger slip is required an external resistance should be added in the secondary circuit.

on the duty cycle: The load "peaks" are greatly reduced and the "valleys" are filled. The power house will be the first part of the steel plant to appreciate such an improvement; or, if the power is purchased the reduction of the maximum demand from 13,300 h.p. to 5500 h.p. may mean a net saving of a great many dollars per month.

Effect on the Size of Motor

But this is not the only advantage of the flywheel. Let us examine the original duty cycle, assuming that no flywheel is furnished. What size motor should be used to drive this mill?

There are two factors that decide this question: the heating of the machine and the maximum torque that it is capable of developing. The heating produced by the original duty cycle, Fig. 3, is considerably more than that corresponding to the average load; this is easily understood when one recalls that the heating is proportional to the *square* of the load; manifestly the *average heating load* or the *root mean square* of the duty cycle is always higher than the average load and increases rapidly with an increase of the peaks. Thus in our case, the r.m.s. is 4000 h.p., whereas with a flywheel the r.m.s. of the duty cycle is only 2800 h.p. The average load is close to 2500 h.p. in either case.

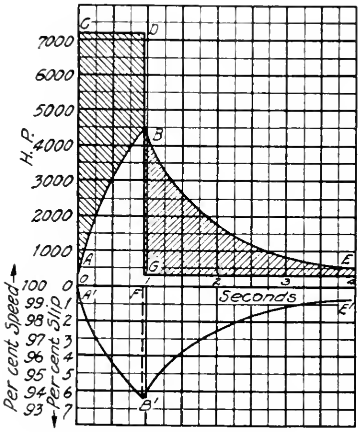

Fig. 4. Effect of the Flywheel on the Motor Load and Speed

But it will not be feasible to drive the mill even with a 4000-h.p. motor without using a flywheel. Every motor has only a limited maximum overload capacity, even for an instantaneous load; in the case of an induction motor if the load exceeds a definite value for each machine, the latter will stall. This stalling or "breaking-down" load is usually around 250 per cent of the normal for mill motors. In case of direct-current motors the limit is usually set by the commutation and the 250 per cent value is very seldom exceeded.

Assuming 250 per cent as the maximum permissible load, and knowing that the maximum peak of duty cycle, see Fig. 3, is 13,300 h.p., it may be easily seen that no motor smaller than 5500 h.p. can be used for driving this mill. It would be safer to install a motor of at least 6000 h.p. to take care of occasional greater overloads. With the use of a flywheel the peak load was reduced from 13,300 h.p. to 5600 h.p.; the selected 3500-h.p. motor is capable of developing 9000 h.p. momentarily.

In other words, the flywheel has permitted us in this case to reduce the motor size; the drive is not "overmotored;" *the average power-factor is therefore higher.*

This is the second big factor in favor of the flywheel application.

Cost of Flywheel Operation

The reader must have noticed that the flywheel has reduced the peak load, but that the average load is not reduced. Obviously, *the flywheel does not generate power—it only redistributes it.* When its speed drops from say, 100 per cent to 85 per cent, the wheel gives out so much energy, but it takes just that amount to bring the speed back to its original value. As long as the speed remains within that range, the flywheel energy will only circulate back and forth, but the amount of power drawn from the line and registered by the watthour meter will not be reduced.

The flywheel is not like a bank that pays interest on the deposited money; it may be rather compared to a broker, retaining commission for each operation—buying or selling alike. And we should now look into the nature of this "commission" to determine under what conditions we are justified in paying it.

In the first place a heavy flywheel needs large bearings, and this increases the friction losses; together with the windage these losses are present whether the mill is rolling steel or is running light. These losses are piling up and present an appreciable item in the monthly bill.

Then, the heavy wheel itself costs money. An extra ton of weight means so many more dollars in the first cost. Large bearings are expensive and the cost of their maintenance and of the oil is higher.

These considerations limit us in going too far in selecting a heavy flywheel.

But we know that a smaller wheel is capable of giving out as much energy as a larger one, provided it is allowed a respectively greater speed reduction.

What is the maximum permissible reduction of speed?

The steel mill operators will be the first to protest against poor speed regulation of the mill drive. Other conditions being equal, the greater the speed reduction the lower will be the average speed, and the lower the speed the smaller will be the tonnage rolled. We should not go beyond 15 per cent in speed regulation in order to maintain good rolling conditions.

The electrical department will be the next to object to an excessive reduction in speed. They know that the larger is the motor slip the more are the secondary, or the so-called rheostat, losses of the motor. For instance, when the power transmitted to the rotor is 1000 h.p., and the slip is 10 per cent, only 900 h.p. are developed as mechanical power on the motor shaft—the other 100 h.p. go as waste heat, dissipated in the secondary resistance. By increasing the *average slip* by, say 5 per cent, we decrease the motor efficiency by a like amount. The kw-hr. per ton of steel rolled will go up—and so will the power bill. The increased power consumption per ton means that the average demand will be somewhat higher if the same tonnage is obtained—or if the average demand will be the same, the mill tonnage will be reduced.

This is the "commission" which is paid for the flywheel assistance. We should be certain always that we gain not less than we pay for.

Application and Misapplication of Flywheels

A good example of a duty cycle where flywheels do not pay for themselves is shown in Fig. 5; it represents rolling on a continuous mill. Due to the sustained load, the flywheel would not reduce the peak; the r.m.s. values are practically the same—the motor size cannot be reduced, and then the question may rightly be asked: What is the use of going to the expense of installing a flywheel on such a mill and having the increased secondary and friction losses, when, on the other hand, no benefit may be derived from its operation?

This question is usually answered in the negative, and hardly any continuous mills or rod mills are equipped with flywheels.

There are certain classes of mills the duty of which always require flywheels; such, for example, as the plate and sheet mills, 3-high bloomers and the like. But there are other mills that do not lend themselves to any hard and fast rules. Take for instance a piercing mill of a tube plant: the duty is severe; only one piece is in the mill at a time and the high load peaks alternate with the light friction load; one is apt to conclude that this would be an ideal application for flywheels. However, the majority of piercing mills are not equipped with wheels, and rightly so.

When the billet to be pierced is short, the whole operation takes only 2, 3, or 4 seconds and the flywheel will very materially assist the motor; piercing mills doing this kind of work should be and usually are flywheel-equipped. But when the piercing of one billet lasts for 20 or 30 seconds the flywheel will be all "used up" after, say 5 or 6 seconds, and for the rest of the period the line input will be about the same as if no wheel were used,. unless, of course, we make a flywheel of non-commercial size and weight. Therefore most of the piercing mills run without flywheels.

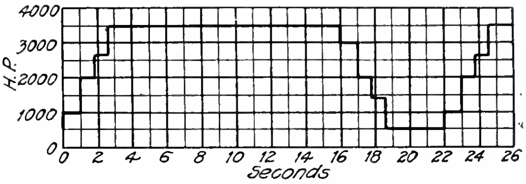

Fig. 5. Typical Duty Cycle of a Continuous Mill. Flywheels are of little use for such duty

Thus we see the importance not only of the magnitude of the load peak, but also of its duration. The same flywheel obviously does much more good in case (a), Fig. 6, than in case (b), although the first peak is much higher than the second one. This explains very well why it is a mistake to speak of a certain flywheel as capable of "clipping" say, 1000 h.p. off the peak load; such a definition means nothing at all unless the duration of the peak is given.

What determines the capacity of the flywheel is the total amount of stored energy, or that part of it which the wheel is capable of giving out within a certain range of speed; the energy, shown by the shaded area in Fig. 4 is expressed in horse power seconds and not in horse power, and it is thus that the capacity of the flywheel should also be expressed.

The only proper way of deciding whether a mill should have a flywheel or not—is to study the duty cycle. If the peaks are only 150 per cent, or less, of the normal, and are sustained, then the chances are that the use of a flywheel will not be a paying proposition.

The smaller the drive the less important obviously is the question of a reduction of peaks. On the other hand, the more limited the generating capacity of the steel mill power plant or the higher the maximum demand rates of the power company, the more advantageous becomes the applications of flywheels.

Steam and Electric Drives

Only a few words are necessary to point out how different are the reasons for equipping steam engines and electric drives with flywheels.

A reciprocating steam engine has not, and cannot have, an inherently uniform crank effort; obviously, the torque produced by a steam engine varies quite appreciably during one revolution, depending on the position of the pistons. A single cylinder engine could not pass the dead centers if not assisted by the stored energy of the rotating masses. On this account, even with a perfectly uniform load, the steam engine would vary its speed during one revolution, if not furnished with a flywheel of proper capacity. Thus, in this case, the flywheel is needed primarily to correct the inherently poor speed regulation of the drive, and only secondarily for the load equalization.

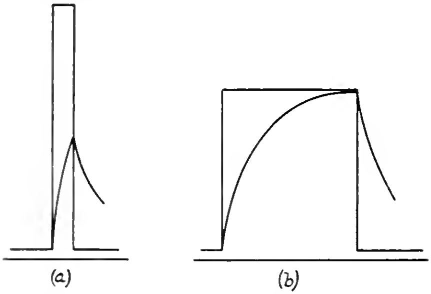

Fig. 6. Influence of the Duration of Pass on the Effect Produced by the Flywheel

With electric drive the problem is entirely different. The torque produced by the motor is uniform; there are no dead centers; the motor speed regulation is so good that it is necessary to increase it artificially in order to utilize the flywheel; thus the latter is not needed for correcting some inherent deficiencies of the drive, but for the single purpose of equalizing the load.

FLYWHEEL CALCULATIONS

After the general purpose of flywheel applications to mill drives has been made reasonably clear, it may be worth while to show briefly by a few concrete examples how the various flywheel calculations can be made.

Total Stored Energy

Assume a large flywheel having a $WR^2 =$ 15,000,000 lb-ft.^{2} (i.e., an effect of 15,000,000 lb. at 1 ft. radius or of 3,750,000 lb. at 2 ft. radius, etc.) and a wheel speed of 83 r.p.m. What is the total amount of energy stored in the wheel?

The energy (E) possessed by any body of weight W lb. moving with a velocity of V ft. per sec. is

$$E = \frac{W \times V^2}{32.16 \times 2} \text{ft-lb.} \qquad (1)$$

(32.16 ft. per sec. is the rate of gravity acceleration). The rotating flywheel with a given WR^2 and running at n r.p.m. may be considered as a body with weight W moving with the same velocity as the end of its radius of gyration R; this velocity in ft. per sec.

$$V = \frac{2\pi R \times (\text{r.p.m.})}{60} \qquad (2)$$

Substituting this value in (1), obtain

$$E = \frac{W \times (2\pi R)^2 \times (\text{r.p.m.})^2}{2 \times 32.16 \times (60)^2} = \frac{WR^2 \times (\text{r.p.m.})^2}{5865} \text{ ft-lb.} \qquad (3)$$

In the example

$$E = \frac{15{,}000{,}000 \times 83^2}{5865} = 17{,}500{,}000 \text{ ft-lb.}$$

This energy is strictly equal to the amount of work which was required to bring the flywheel from rest to the speed of n r.p.m.

As

$$1 \text{ h.p.-sec.} = 550 \text{ ft-lb.} \qquad (4)$$

$$E = \frac{WR^2 \times (\text{r.p.m.})^2}{3{,}226{,}000} \text{h.p.-sec.} \qquad (5)$$

$$= 31{,}900 \text{ h.p.-sec.}$$

We note that these formulas express the well known facts: the stored energy is proportional to the WR^2 of the wheel and to the second power of its speed.

Amount of Energy Available for Regulation

The energy as calculated above is the *total* amount stored in the wheel at a certain speed. How much of this amount may be used for load equalization in case the flywheel is installed at the mill drive?

We will assume that a speed variation of more than 15 per cent is not permissible, i e., in this case the wheel speed will vary from 83 r.p.m. (max.) to 70.5 r.p.m. (min.). At 70.5 r.p.m. the stored energy will be, as per equation (5):

$$E_2=\frac{15,000,000\times 70.5^2}{3,230,000}=22,950 \text{ h.p.-sec.}$$

Thus the energy given out is:

$$31,900-22,950=8950 \text{ h.p.-sec.}$$

or approximately 28 per cent of the total.

Thus it is evident that the per cent of energy given out is not directly proportional to the per cent of speed reduction. On this account it is advisable to give the general relation between the two values.

Suppose that the flywheel WR^2 drops its speed from n_1 r.p.m. to n_2 r.p.m. The speed reduction (s) expressed as a fraction of the maximum operating speed (n_1) is:

$$s=\frac{n_1-n_2}{n_1} \qquad (6)$$

or, the minimum speed is:

$$n_2=n_1\times(1-s) \qquad (7)$$

Now, the total amounts of stored energy at wheel speeds of n_1 and n_2 r.p.m. are:

$$E_1=\frac{WR^2\times n_1^2}{3,226,000} \text{ h.p.-sec.}$$

and

$$E_2=\frac{WR^2\times n_2^2}{3,226,000} \text{ h.p.-sec.}$$

respectively.

Hence the energy given out comprises the following portion of the total:

$$\frac{E_1-E_2}{E_1}=\frac{n_1^2-n_2^2}{n_1^2} \qquad (8)$$

Transposing:

$$\frac{E_1-E_2}{E_1}=\frac{n_1-n_2}{n_1}\times\frac{n_1+n_2}{n_1}=s\times\frac{n_1+n_1(1-s)}{n_1}=$$

$$s\times(2-s)=2s-s^2 \qquad (9)$$

Giving s (speed reduction) various values from 0 to 1 (or from 0 to 100 per cent) we may calculate the corresponding portions of the total energy given out. These calculations are shown in Fig. 7. For instance, if the speed reduction is 12 per cent ($s=0.12$) the flywheel gives out approximately 22.5 per cent of the total energy available at the maximum speed. It is worth noting that at the beginning of retardation for one per cent drop in speed more energy is given out than when the wheel was previously retarded. At 50 per cent speed reduction, three quarters of the total energy is already used up.

Acceleration and Retardation of the Flywheel

Example 1

Assume that the wheel should be accelerated at a uniform rate from n_2 r.p.m. to n_1 r.p.m. in t seconds. Hence the rate of acceleration will be

$$a=\frac{n_1-n_2}{t} \text{ r.p.m. per sec.} \qquad (10)$$

If the inertia of the wheel is WR^2 lb-ft.² then there will be required during this period an uniform accelerating torque

$$T_a=\frac{WR^2\times a}{308} \text{ lb-ft.} \qquad (11)$$

For instance, if the same wheel, as was considered above ($WR^2=15,000,000$ lb-ft.²), is to be brought from rest ($n_2=0$) to $n_1=83$ r.p.m. in 10 seconds, then the required torque

$$T_a=\frac{15,000,000}{308}\times\frac{83}{10}=405,000 \text{ lb-ft.}$$

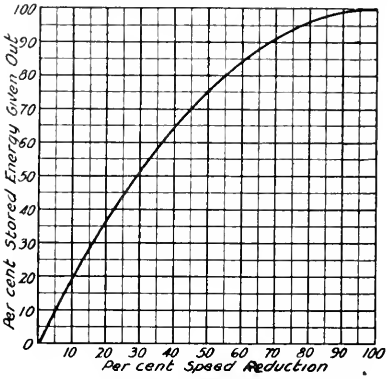

Fig. 7. Energy Given Out by a Flywheel at Various Reductions of Speed in Per Cent of the Total Energy at Maximum Speed

If the flywheel must be brought to this speed by an 83-r.p.m. motor, the latter will have to develop during the acceleration a torque (in addition to the friction torque) which corresponds to a

$$\frac{405,000\times 83}{5250}=6440 \text{ h.p. load.}$$

Example 2

Assume now that the same flywheel, as considered in Example 1, runs at 83 r.p.m. and its speed is then reduced to 50 r.p.m. at a uniform rate, in 3 seconds.

When it is slowing down the flywheel gives out some of its energy. Therefore no torque is required to drive it but, on the contrary, the wheel itself develops a torque. What does this torque amount to?

The rate of acceleration is

$$a=\frac{50-83}{3}=-\frac{33}{3}=-11 \text{ r.p.m. sec.}$$

(a is negative and we therefore call it "retardation"). Use the same formula (11), as before and determine

$$T=\frac{15{,}000{,}000\times 11}{308}=535{,}000 \text{ lb-ft.} \qquad (11a)$$

Induction Motor Characteristics

The majority of all mills equipped with flywheels are driven by induction motors. For this reason little need be said to remind the reader of some fundamental characteristics of these machines, in order to make the discussion clearer.

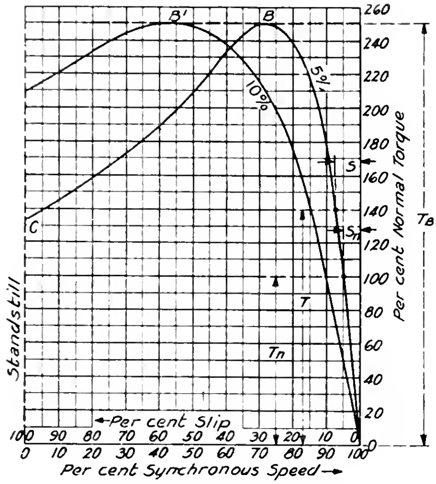

Fig. 8. Slip-torque Characteristic of Induction Motors

Fig. 8 shows the speed-torque curve (OBC) of an induction motor with a fixed resistance in its secondary. Starting at small values (point O) the slip at first increases proportionally to the torque; then the curve bends over until, at point B, the torque begins to decrease with the increasing slip. Torque T_B is the breaking-down torque of the motor. We have previously mentioned that it is usually about two and one half times the normal torque (T_n) for mill motors. If the load exceeds T_B—the motor will stall.

Within the operating range the speed-torque or the slip-torque curve is very nearly a straight line; this is especially true in our case, when flywheels are used for the express purpose of reducing the maximum load on motors. This fact explains why we assume in our reasoning that the motor torque is proportional to its slip.

If, for instance, our motor has an instantaneous value of slip — s (Fig. 8) then it develops at that instant the torque

$$T=\frac{T_n}{s_n}\times s \qquad (12)$$

where T_n and s_n are the normal torque and slip.

If the secondary resistance is changed, another curve (for instance OB^1) will represent the slip-torque relation. However, the value of the breaking down torque T_B will not be affected by this change.

Assume now that an induction motor, having a synchronous speed of $n_s=600$ r.p.m. runs with a slip $s=0.05$, and develops a torque $T=8750$ lb-ft. With a slip of 5 per cent, the motor speed is

$$\begin{aligned} n &= n_s\ (1-s) \qquad (13)\\ &=600\ (1-0.05)=570 \text{ r.p.m.} \end{aligned}$$

The horse power P, developed at the motor shaft is,

$$\begin{aligned} P &= \frac{T\times n}{5250} \qquad (14)\\ &= \frac{8750\times 570}{5250}=950 \text{ h.p.} \end{aligned}$$

But this P is only the mechanical power developed by the motor at its shaft; it is less than the power input from the line, as measured by the wattmeter (we will call it P_2) because part of this input will be lost as copper loss and core loss in the stator of the machine; the remaining balance (P_s) is then transmitted magnetically through the air-gap to the rotor. For a given line input P_2 the power P_s has a definite value.

But even the power transmitted to the rotor (P_s) is not entirely converted into mechanical power at the shaft. When the motor runs with a slip there exist secondary losses, which are approximately proportional to the slip; with, say, 5 per cent slip, 5 per cent of the power P_s may be assumed as lost on that account.

The secondary losses are partly in the rotor winding and iron, but with an external permanent resistance the bulk of these losses is outside the motor and may be charged to the use of this resistor.

After the secondary losses are subtracted from P_s the balance is the mechanical power at the motor shaft (P):

$$P = (1-s)\times P_s \tag{15}$$

$$P_s = \frac{P}{1-s} = \frac{950}{0.95} = 1000 \text{ h.p.} \tag{16}$$

The secondary losses

$$P_r = P_s \times 0.05 = 50 \text{ h.p.} \tag{16-a}$$

Thus the power P_s is the sum of the shaft output and of the secondary losses. It is clear from (14) and (15) that

$$P_s = \frac{T \times n_s}{5250} \tag{17}$$

The value n_s (synchronous speed) is a constant; therefore the torque T and the power P_s are always proportional to each other, regardless of the actual (mechanical) speed. For that reason P_s is quite frequently (but not accurately) called "the h.p-torque;" this means, that P_s is the horse power that the motor would develop delivering the torque T, but running at synchronous speed. More properly it should be called the "equivalent h.p.," because it is the measure of the heating load imposed on the machine, regardless of whether it runs with a small or large slip.

Starting from rest, and drawing normal current from the line the motor at first does not develop any power at the shaft (because the speed is zero) but the secondary losses are high (see Fig. 9). With the increased speed (the torque remaining constant) the losses are being reduced and the mechanical power increases. The "equivalent h.p." P_s is constant throughout this period, as also is the line input.

If the motor is running and we introduce more resistance in the secondary, maintaining constant line input, we shall observe that the speed n and the mechanical (shaft) power P, see (13) and (15), both decrease in the same proportion; this means, of course, that the torque T is not changed.

Assume that we increase, in the above example, the motor slip to 10 per cent; then

$$P_s = 1000 \text{ h.p., as before}$$

$$n = 600 \times .90 = 450 \text{ r.p.m.}$$

$$P = 1000 \times 0.9 = \frac{900}{540} \text{ h.p.} = 8750 \text{ lb-ft.},$$

which is the old value.

This is a very important conclusion; it means for instance, that when an induction motor drives a mill *without any flywheel* and is called upon to develop a certain torque (for instance when taking a certain draft on a certain billet) nothing is gained by increasing the secondary resistance; as long as the torque requirements are the same, the increased resistance only means lower speed, proportionally smaller mechanical horse power and respectively higher secondary losses; but the total power and therefore the line input will be the same as mentioned previously. It is clear enough now that a drive without a flywheel does not have to have any external permanent resistance; the speed regulation does not need to be as large as with a flywheel.

Motor Load Curves

We have shown in Figs. 3 and 4 the influence of the flywheel on the motor load, and have explained in a general way why the motor load is represented by the curves of the given shape. It is necessary now to show how these curves are actually calculated.

Assume a mill being driven by an induction motor of P horse power and n r.p.m. (synchronous speed). The mill is running light and the motor is developing only the friction torque T_0. Then the metal enters the rolls and this imposes a combined torque T_1. (See Fig. 10.) The torque developed by the motor (T) will gradually increase, as we know, along some curve AB.

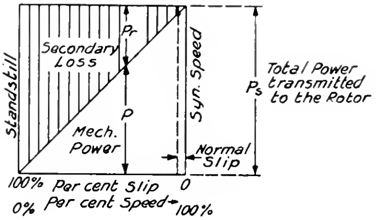

Fig. 9. Relative Proportion of Mechanical Power and Secondary Losses of an Induction Motor at Various Values of Slip

What is this motor torque after, say, t seconds?

At any instant the external torque T_1 is counter balanced by two torques:

T = Motor torque to be determined.
T_{fw} = Torque developed by the retarding flywheel.

In other words:

$$T_1 = T + T_{fw} \tag{18}$$

If the motor develops the torque T, it means that the slip at that instant is, see (12),

$$s = s_n \times \frac{T}{T_n} \tag{19}$$

or

$$T = \frac{T_n}{S_n} \times s \qquad (20)$$

The torque delivered by the slowing-down flywheel of known flywheel effect (WR^2 in lb-ft.^{2}) depends exclusively on the rate (a) in r.p.m. per sec. at which it retards; we have shown previously in one example how to calculate it. (See 11-a).

It equals

$$T_{fw} = \frac{WR^2 \times a}{308} \qquad (21)$$

What is the rate of retardation a? So far all that we know about it is, that it is not a constant value throughout the entire period; this makes it necessary to consider its instantaneous value at any selected instant, and not merely the average. When the time (t) increases slightly by a very small quantity (dt), see Fig. 10, the slip increases also by a very small quantity (ds); the respective change of speed is obviously

$$n_s \times ds \qquad (22)$$

If the speed changes thus in (dt) seconds, it means that the rate of acceleration is

$$a = n_s \times \frac{ds}{dt} \qquad (23)$$

and therefore the torque developed by the flywheel, see (21), is

$$T_{fw} = \frac{WR^2 \times n_s}{308} \times \frac{ds}{dt} \qquad (24)$$

Hence, see (18), (20), (24);

$$\frac{WR^2 \times n_s}{308} \times \frac{ds}{dt} + \frac{T_n}{s_n} \times s = T_1 \qquad (25)$$

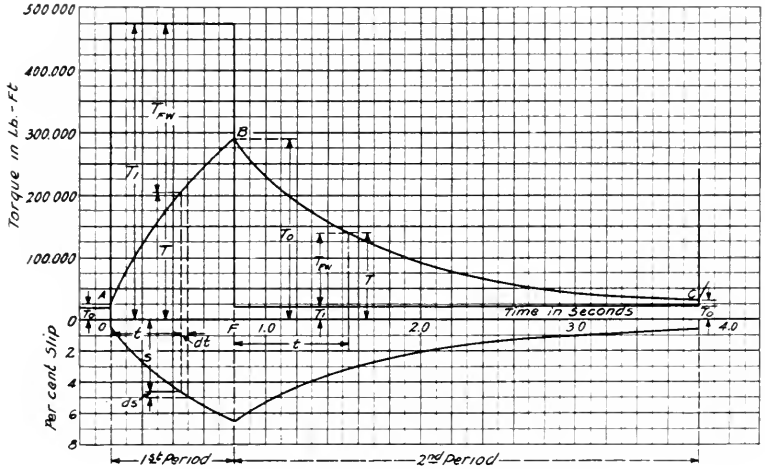

Fig. 10. Study of Flywheel and Motor Performance

In this equation only s and t are unknown and variable; the other quantities have a definite and constant value throughout the period under consideration. We must determine from (25) how the slip s changes with time t, and if we know the slip it is the same as if we knew the motor torque T.

Now, the equation (25) cannot be solved with elementary mathematics. It is a so-called linear differential equation and it would be outside the scope of this article to show how it is solved. We shall therefore write the answer directly:

$$T = T_1 - \frac{T_1 - T_0}{e^{At}} \; (*) \qquad (26)$$

where

$$A = \frac{308 \times T_n}{WR^2 \times n_s \times s_n} \qquad (27)$$

The expression (26) is the so-called formula of Gasche, used since 1910 for flywheel calculations. The value of A is a constant for a given motor and flywheel, provided the secondary resistance is permanent (otherwise the value of *normal* slip s_n will change). We shall call A the "motor-flywheel constant;" once determined it will be used throughout the calculations for the same drive.

Example 1

A short example will illustrate this method and will show how simple are its applications.

Let:

Motor rating, 3500 h.p.

Synchronous speed, $n_s = 83.3$ r.p.m.

Synchronous torque,

$$T_n = 5250 \times \frac{3500}{83.3} = 221{,}000 \text{ lb-ft.}$$

(*) $e = 2.718$, is the base of natural logarithms.

Normal slip (with 5 per cent resistance) $s_n = 0.05$.

Flywheel effect, $WR^2 = 15,000,000$ lb-ft.^{2}

Thus the motor-flywheel constant is, per (27):

$$A = \frac{308 \times 221,000}{15,000,000 \times 83.3 \times 0.05} = 1.1$$

We shall see how this drive will behave during the pass shown in Fig. 10.

The initial motor load at the beginning of the pass depends, of course, on the previous conditions; when the rolling just begins after a considerable time interval, the initial load equals the friction load; in a more general case, the initial load may be higher. In this example we shall assume that when the pass begins the motor did not regain as yet its no-load speed and that it was developing about 400 h.p., or

$$T_0 = 25,000 \text{ lb-ft.}$$

The external load imposed on the mill including friction is

$$T_1 = 475,000 \text{ lb-ft.}$$

(equivalent to 7530 h.p. at 83.3 r.p.m.).

The calculations made in accordance with (26) are tabulated in Table I, and plotted in Fig. 10.

The values of e^{At} were read from the curve Fig. 11, plotted on semi-logarithmic paper, against respective values of At.

The *2nd Period*, as included in Table I, covers the time when the metal is out of the rolls and when the motor is regaining its speed. Exactly the same formula (26) is used for this part of the calculations as for the *1st Period*. The definitions are shown in Fig. 10; for the 2nd Period, the "external" torque T_1 = friction torque; the "initial" torque T_0 = torque at point B; the time is, of course, measured from point F.

Ordinarily it is not necessary to calculate as many points as was done in the tabulation. It is most important of all to find the motor load at the end of the periods (B and C) and for quick calculations this is sufficient. The next period will start from C, with initial torque $T_0 = 29,900$ lb-ft., and by calculating two points similar to B and C for each pass a fairly complete picture of the performance will be determined.

Example 2

Assume now another case: how to determine the size of the flywheel, if the motor peak load is to be limited to a predetermined value?

TABLE I

	1	2	3	4	5	6	7	8	9	10
Period	Elapsed time t	Flywheel Constant A	At	e^{At}	Initial Motor Torque T_0	External Torque T_1	$\frac{T_1-T_0}{e^{At}}$	Motor Torque $T = T_1 - \frac{T_1-T_0}{e^{At}}$	Equivalent h.p. load $\frac{T \times n_s}{5250}$	Motor Slip $S = \frac{s_n}{T_n} \times T$
1st Period:										
Load on Drive slows down	0	1.1	0	1	25,000	475,000	450,000	25,000	397	0.57
	0.2	1.1	0.22	1.25	25,000	475,000	360,000	115,000	1825	2.60
	0.4	1.1	0.44	1.55	25,000	475,000	290.000	185,000	2940	4.19
	0.6	1.1	0.66	1.92	25,000	475,000	234,000	241,000	3820	5.45
	0.8	1.1	0.88	2.4	25,000	475,000	187,000	288,000	4570	6.52
2nd Period:										
Load off Drive regains its speed	0	1.1	0	1	288,000	19,000	−69,000	288,000	4570	6.52
	1.0	1.1	1.1	3.0	288,000	19,000	−89,700	108,700	1720	2.46
	2.0	1.1	2.2	9.0	288,000	19,000	−29,900	48,900	775	1.11
	3.0	1.1	3.3	27.0	288,000	19,000	−10,000	29,000	460	0.66

We shall consider the same mill and motor as before. The external load (Fig. 12) is $T_1 = 400,000$ lb-ft.; it lasts for 2.1 sec.; the initial motor torque is $T_0 = 25,000$ lb-ft. How big should the flywheel be to limit the motor load to, say, 150 per cent normal?

The maximum motor load during this period will occur at the end of the pass, that is, after $t = 2.1$ sec. Its value should not be more than

$$T = 1.5 \times 221,000 = 331,500 \text{ lb-ft.}$$

Substitute these values in (26), and determine e^{At}:

$$e^{At} = \frac{T_1 - T_0}{T_1 - T} = \frac{400,000 - 25,000}{400,000 - 331,500} = \frac{375,000}{68,500} = 5.5$$

From curve, Fig. 11, we shall find that for $e^{At} = 5.5$,

$$At = 1.72$$

and therefore, for $t=2.1$

$$A=\frac{1.72}{2.1}=0.82$$

Substitute this value in expression (27) to determine the flywheel effect WR^2:

$$WR^2=\frac{308\times T_n}{A\times n_s\times s_n}=\frac{308\times 221{,}000}{0.82\times 83.3\times 0.05}=$$
$$20{,}000{,}000 \text{ lb-ft.}^2$$

MEANS OF VARYING THE SECONDARY RESISTANCE

Effect of Secondary Resistance on Load Curves

We have heretofore assumed that the motor secondary resistance is 5 per cent. What will be the effect on the load curves if we increase this resistance to any other value, say, 10 per cent?

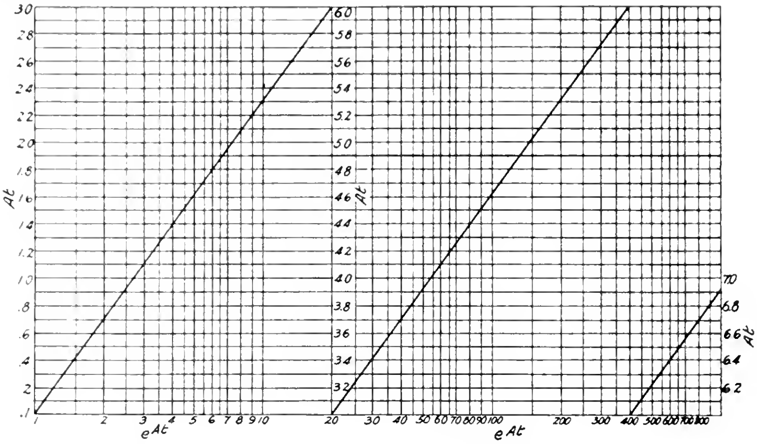

Fig. 11. Curve Giving Values of e^{At} for Different Valu

This value is, of course, the theoretical minimum that should be used under these circumstances. It is interesting to compare the two examples. Whereas in Example 1 the external load is higher, and the flywheel is smaller, still the maximum motor load is only 285,000 lb-ft. or 128 per cent normal, as against 150 per cent in Example 2. The obvious reason for this is, that the duration of the pass was increased from 0.8 sec. to 2.1 sec.

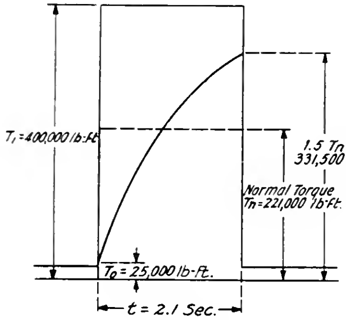

Fig. 12. Case Considered in Example 2

It will be shown in the following how to obtain the same reduction of load peaks with a smaller wheel.

Before making the calculations, let us reason as follows:

With a larger secondary resistance the motor acquires a more pronounced drooping speed characteristic; thus the flywheel delivers more work, and the motor's share of the load is smaller. In other words, the motor more readily "yields" to the load and "relies" in a greater degree on the flywheel to carry it.

This reasoning is fully sustained by the following example:

The same motor and flywheel are considered as in Example 1. The initial motor load $T_0=30{,}000$ lb-ft., the imposed external load $T_1=425{,}000$ lb-ft., the duration of pass $t=2.5$ sec. Similar calculations, as shown in Table I, were made both for 5 per cent and 10 per cent resistance and plotted in Fig. 13. It is obvious how the change of resistance affects the calculations: with 10 per cent resistance the normal slip is: $s_n=0.10$ instead of $s_n=0.05$ and therefore the "flywheel constant" A (see 27) is one half of its former value. Therefore the quantities At, e^{At}, and finally T will be the same for 10 per cent resistance as for 5 per cent, but at the time $2t$ instead of t. Hence the simple rule for re-plotting the motor load curve from "5 per cent" to "10 per cent:" double the abscissae: $CB=2\times CA$, as shown in Fig. 13; repeat this for several points, and this will determine the "10 per cent" curve during the rolling period. If the secondary resistance is not doubled, but changed in some other ratio, then the abscissae should be changed in that same proportion.

The increased resistance reduced the maximum peak from 392,200 lb-ft. (equivalent to 6200 h.p.) to 324,000 lb-ft. (5140 h.p.) or from 177 per cent to 146 per cent of normal. The average slip values are 6.5 per cent and 9.7 per cent respectively. On the other hand, with the doubled resistance, the maximum slip is 14.6 per cent instead of the former 8.85 per cent; this means that the flywheel has spent (see Fig. 7) 27 per cent of its total stored energy instead of only 17 per cent; the motor is "lazy," especially at the beginning of the pass, when it carries for nearly 1.25 seconds (out of the total 2.5 seconds) less than its rated torque. With a 5 per cent resistance the motor load reaches its normal value in a fraction of a second (0.6 sec.) and this accounts for the fact that less energy is extracted from the flywheel, i.e., more of it is left for use during the next passes. The rheostat losses are calculated and plotted in Fig. 13; they amount, *for one pass* to 0.306 kw-hr. with 5 per cent resistance and to 0.446 kw-hr. with 10 per cent resistance. Thus we arrive at an obvious conclusion: it is desired to have a small resistance at the beginning of the pass, in order to let the motor do the work, to keep the average rolling speed high and the secondary losses low. But when the gradually increasing load reaches a certain value, say, 150 per cent, normal, it is desired to increase the resistance in order to prevent the load from exceeding that value.

Notching-back Method

This desired end is obtained very simply by the use of a so-called "notching-back" relay, which acts as follows:

The regulating resistance in the rotor circuit is subdivided in two parts, each of them amounting to, say, 5 per cent. The first block of resistance always remains in the circuit—hence its name—"permanent resistance." The second part is normally short circuited by a contactor; but when the motor load exceeds the predetermined value, a "notching-back" relay causes that contactor to trip, thus throwing the additional secondary, and cutting down the motor load to one half at that instant.

Fig. 13 illustrates this performance. At point K the motor load reached 150 per cent of normal, its slip is 7.5 per cent; the notching-back relay inserts another 5 per cent in the circuit, making a total of 10 per cent. Now an induction motor, with 10 per cent resistance, running at 7.5 per cent slip cannot carry more than three quarters of its normal load, and therefore the load drops instantly to point L, which is 75 per cent of normal (or one half of the load K). From point L the motor load builds up as per line LM, which is nothing else but the previously plotted "10 per cent" line PQ, only moved to the right over the distance PL. At the end of the pass the load is 297,000 lb-ft. (4710 h.p.) or 134 per cent normal. The maximum slip (at point M) is 13.4 per cent, the stored energy given out is 25 per cent. The average slip during rolling is 7.6 per cent. The secondary losses for this pass are only 0.365 kw-hr.

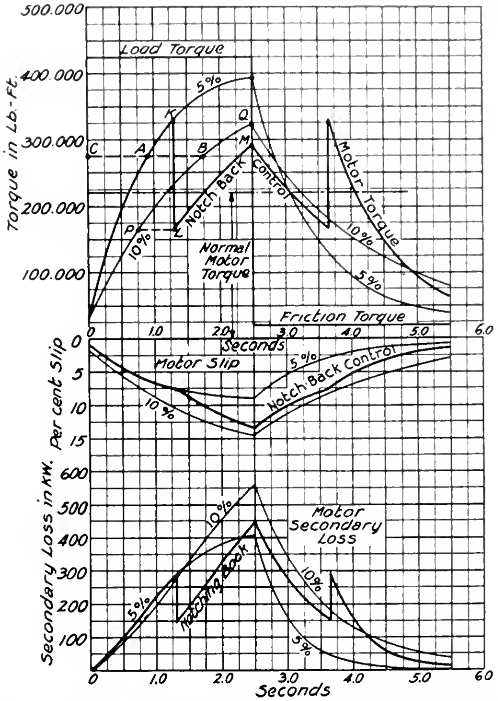

Fig. 13. Motor Load, Slip, and Secondary Losses for Different Values of the Permanent Resistance and Also with the Notching-back Control

General Electric Notching-back Control

A good example of an effective notching-back equipment is shown in Fig. 14.

The mill motor is shown diagrammatically, with reversing switches in the primary and with a part of the secondary control. The permanent resistance *A* is always in circuit; the notching-back resistance *B* is normally short circuited by the contactor *C*, but the latter trips out at heavy loads, actuated by the notching-back relay *D*. The three-phase coil of this relay is energized by the voltage drop across the permanent resistance *A* (when the contactor *C* is closed, the potential at points L_1, L_2, L_3 is the same as at points K_1, K_2, K_2). In other words, the magnetic flux of the notching-back relay is proportional to the secondary current of the motor, i.e., to the kw. load and not to the kv-a. input to the machine.

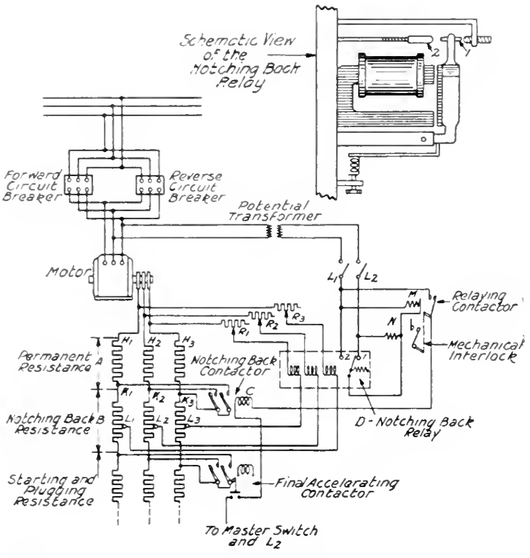

Fig. 14. Wiring Diagram of the General Electric Notching-back Control as Applied for Steel Mill Drives. The insert shows schematically the new notching-back relay

When the relay is not energized, its contact *1* is closed; this energizes the relaying contactor *M*, which keeps the notching-back contactor *C* closed; the contactor *N* is at that time open not only because it is mechanically interlocked with *M*, but also because both ends of the coil *N* have the same potential.

When the motor load reaches the predetermined value, the relay *D* picks up, the contact *1* breaks and the relay armature moves from *1* to *2*. Quick as this movement is, we may distinguish the following separate phases of it:

The opening of the contact *1* does not cause in itself the tripping of the notching-back contactor; the coils of the two relaying contactors, *M* and *N*, are then connected in series across the lines, but while the contactor *M* is closed, and its impedance is high, the contactor *N* is still open and has therefore a lower impedance; for this reason the total line voltage is not divided evenly between the two coils: the voltage across the coil *M* may be more than 90 per cent of the total which causes the contactor *M* to stay closed and *N* to stay open. After the relay armature completes its travel, the contact *2* closes, full voltage is then applied to *N*, and the latter closes; the contactor *M* is tripped; this, in turn, trips the notching-back contactor, throwing additional resistance in the rotor and immediately cuts down the motor load and the secondary current in proper proportion. Although the secondary current is thus reduced, the relay coils are energized from the voltage across a larger resistor, and therefore the relay will stay closed.

After the load decreases below the set value, the voltage drop across H_1-L_1, H_2-L_2, H_3-L_3 becomes insufficient to hold the relay armature. The contact *2* opens and after the *1* closes the contactors *M* and *N* return to their original positions; the contactor *C* cuts out again the notching-back resistor.

Sometimes the load fluctuates close to the relay setting and the armature would pick up and would just make and break the contact *1* without traveling all the way across the air gap to make the contact *2;* such oscillations will not be reflected, however, on the notching-back contactor as is clear from the description of the system. This is the main reason for employing the small relaying contactors *M* and *N*. The tips of the contactor *N* do not carry any current and it is employed merely to provide for the proper functioning of *M*.

The relay setting may be adjusted within wide limits by changing the tension of its spring, by varying the distance between tips and also by adjusting the resistance $R_1-R_2-R_3$. It is customary to set it to trip the notching-back contactor at about 150 per cent load, and to close the latter again when the load goes down to about 75 per cent. The closing of the notching-back contactor will cause the instantaneous value of the load to double (if resistance *B* equals *A*) and it will then decrease gradually.

It is perfectly feasible to have the notching-back resistor subdivided into several sections, each short-circuited by a separate contactor and controlled by a separate relay. The latter should be set at gradually increasing values, so that the secondary resistance is increased with the load in several smaller steps. Practice has shown, however, that such a refinement is very seldom needed, and the one-step notching-back equipment, as described, meets the steel mill requirements quite satisfactorily.

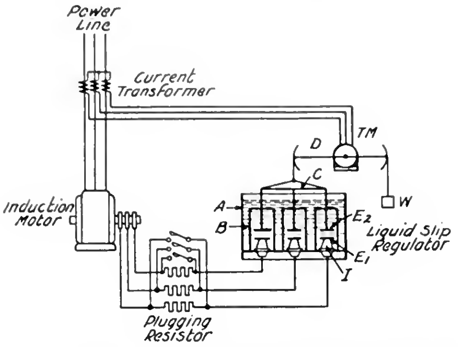

Fig. 15. Elementary Diagram of a Liquid Slip Regulator

Liquid Slip Regulators

There is another device for regulating the secondary resistance with the load in order to smooth out the peaks. This apparatus (see Fig. 15) known as a liquid slip regulator, consists of a tank A, with three insulating pots B. In each pot, mounted on an insulating bushing I, is located a stationary electrode E_1; each of these electrodes is connected to one of the slip rings of the motor. Three movable electrodes E_2, one in each pot, tied together by a cross-bar C_0 are suspended to the lever arms D. These arms are mounted on the shaft of the so-called "torque motor" TM, which is an induction motor with its primary winding connected in series with the main motor lines. The tank is filled with a weak solution of sodium-bicarbonate; the columns of the liquid between the electrodes E_1 and E_2 act as the secondary resistance in each phase, with the cross-bar C serving as the Y-point. Cooling coils are immersed in the tank and water is circulated through them in order to remove the heat produced by the secondary current. The suspended electrodes E_2 are partly balanced by the counterweight W, but the latter in itself is not sufficient to raise the electrodes, which normally occupy the lowest position corresponding to the minimum resistance in the rotor circuit.

When however, the load increases and exceeds a predetermined value, the torque of the motor TM, added to the torque produced by the counterweight W, raises the electrodes E_2, thus inserting more resistance in the secondary. By making the counterweight W heavier, the current value at which the regulator begins its action is reduced, and vice versa. The slip regulator tends to so adjust the secondary resistance as to limit the input to the motor, throwing the balance of the load on the flywheel. During the interval between the passes the slip regulator reduces the secondary resistance and brings the mill gradually to speed.

The same apparatus is intended for "starting duty" of the motor: the maximum resistance, as determined by the maximum distance between E_1 and E_2 should be high enough to limit the starting current to a sufficiently low value. This determines the strength of the electrolyte in the tank; it is not feasible, however, to weaken the solution too much in order to obtain a higher maximum resistance, as by doing so the minimum resistance (when the blades are close together) is also increased, which is of course objectionable. This feature limits the maximum resistance of the regulator.

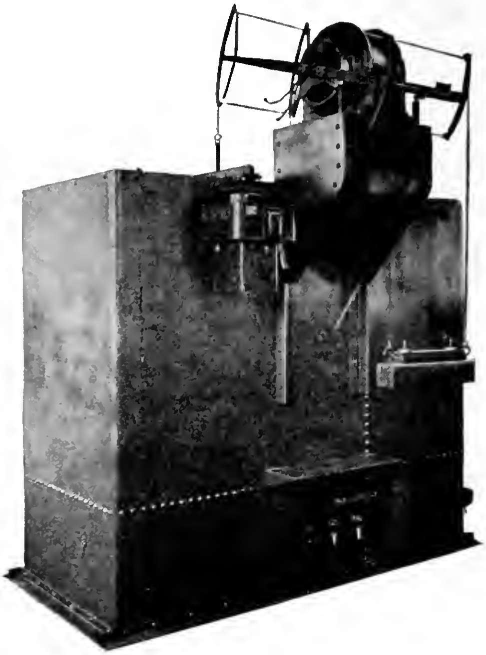

Fig. 16. Liquid Slip Regulator

When the flywheel drive should be quickly stopped, the driving induction motor is "plugged," i.e., the phase rotation is reversed and a counter-torque is thus produced. In such cases in order to limit the current to the same value as at starting, the secondary resistance should be made twice as great; inasmuch as the existing liquid slip regulators cannot give this increased amount of resistance, it is necessary to add an external iron-grid resistor (so-called plugging resistor) normally short circuited by a contactor, but inserted in the circuit when plugging. A liquid slip regulator is shown in Fig. 16.

Slip regulators are universally used in conjunction with flywheel motor-generator sets, such as are employed in large mine hoists and in reversing steel mills. The load equalization obtained in such cases through the use of a slip regulator is very efficient as witnessed by the many actual tests as shown in Fig. 17. The question then naturally arises: why not apply this effective device to the induction motor mill drives equipped with flywheels, instead of using the resistor-contactor control.

This topic was quite a live one of late, various steel mill engineers and electrical manufacturers discussing the comparative merits of the two devices. Unfortunately some of these discussions were conducted on, what may be called, purely partisan lines, and as such did not clear the issue. But this problem, as is the case with many others, can and would be answered correctly if prejudices and beforehand-made-conclusions are set aside and the subject looked into from an engineering standpoint.

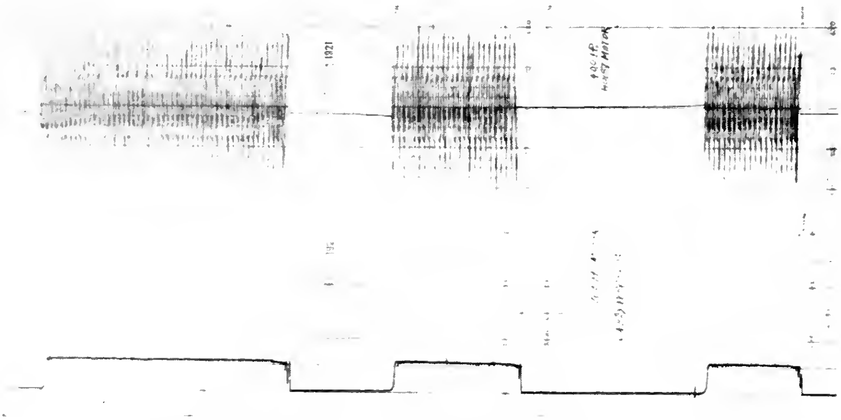

Fig. 17. Load Equalization Obtained on a Large Mine Hoist Equipped with a Flywheel Motor-generator Set and a Liquid Slip Regulator as shown in Fig. 16

Slip Regulators *vs.* Magnetic Control

Assuming that the slip regulator is made sensitive enough it should reduce the load peaks somewhat more spectacularly than the notching-back control previously described. The curve *1* in Fig. 18 is the same load curve which has been plotted in Fig. 13; the curve *2* shows what could be the result of the application of a slip regulator to the same part of the duty cycle.

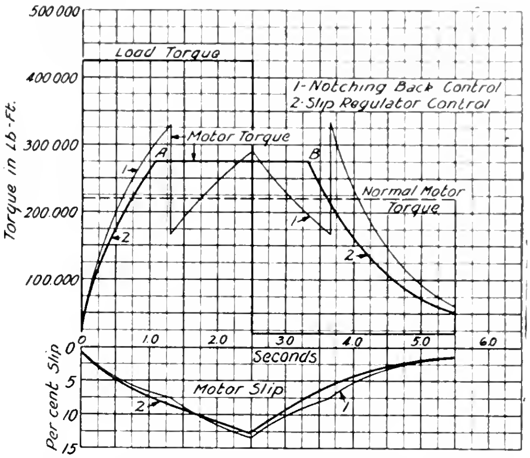

Fig. 18. Comparison Between Performance of a Notching-back Control and that of an Ideal Liquid Slip Regulator

It is to be noted, in the first place, that when the electrodes of the slip regulator are as close together as possible there still remains a quite substantial minimum resistance in the rotor circuit. Manifestly the upper and lower electrodes cannot be brought into direct contact with each other as this would cause them to "freeze." The necessity of using spacers brings the minimum resistance to a value which is very seldom less than 6 or 7 per cent; in other words, the motor has a 6 or 7 per cent permanent resistance which cannot be made smaller as readily as when grid resistors are used. The reduction of the minimum resistance by strengthening the electrolyte is not feasible, as was pointed out previously.

Thus, when the load is imposed on the mill, the line input will build up gradually, see curve 2 (Fig. 18) as it would with any motor having, say, 6 per cent resistance. When the load reaches the setting of the regulator, see point A, the latter will start to move the blades apart. We shall assume that this regulator is very quick-acting and that it will, from this instant on, maintain a constant input, equal to say 125 per cent of the motor rating or any other value depending on amount of counterweight W. During the time between the passes the regulator will bring the electrodes together tending to maintain constant input. At point B the blades are close together and after this point the load will drop off as with any motor having 6 per cent permanent resistance.

The reduction of peaks is obviously in favor of the slip regulator provided it functions as was assumed. What is the possible result of reduction of peaks, in this case from 150 per cent to 125 per cent? It will not affect the motor rating or the maximum torque requirements. It may be of some importance for a small power plant, supplying current to one or two mills, which comprise the bulk of the load. Such a case is conceivable although it is encountered rather as an exception than as a rule. If other things like first cost and maintenance are equal, and the slip regulator is made sensitive enough for steel mill duty, then it would be preferred. Unfortunately a small installation is never a good place to install a slip regulator, as will be explained in the following paragraphs.

But first of all we should analyze whether the slip regulator will meet our expectations.

We have assumed that the slip regulator is so sensitive that its movements follow very closely the rapid fluctuation of the load. There is an inherent limit to this sensitiveness. Essentially, the electrode mechanism of the regulator consists of parts that should be sufficiently rigid to work properly; in other words its weight is far from negligible. This

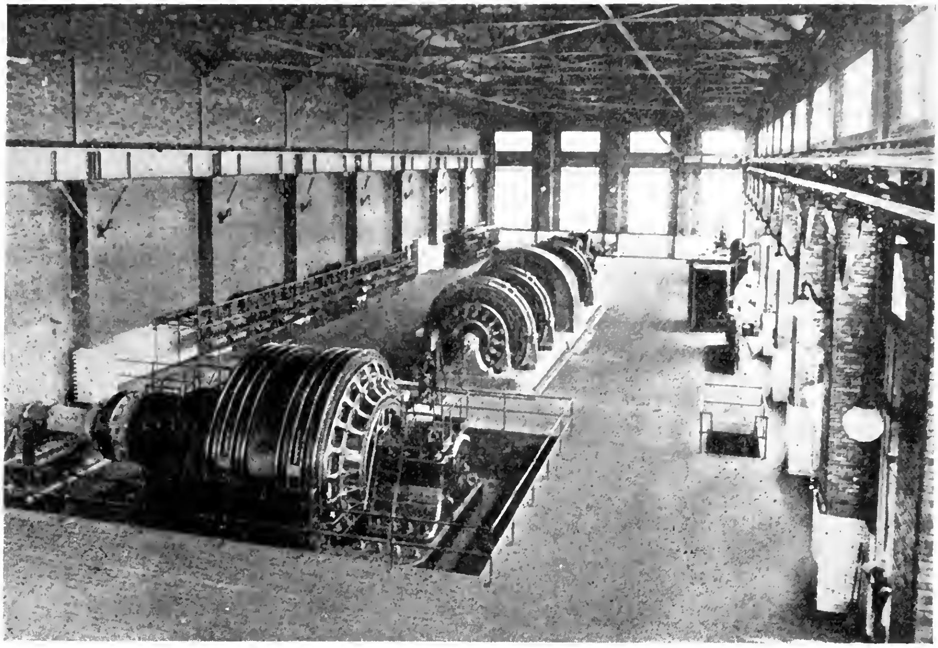

Fig. 19. General View of a Large Reversing Blooming Mill; the Mill Motor is shown in the Foreground and the Flywheel Motor-generator Set Behind it; the Liquid Slip Regulator is Located to the Right of the Flywheel Set

heavy mechanism should be moved quickly first in one, then in the other direction, in order to follow the fluctuations of load. The motive power is the torque motor *TM*, Fig. 15, or to be exact, the excess value of its torque when the current exceeds the predetermined amount. This excess torque should move the electrode mechanism, and it is clear to anyone that with a limited motive force and with a definite weight to be accelerated, the electrodes cannot be moved faster than the fundamental laws of mechanics permit. This limits the minimum time in which the electrodes can cover a certain travel, even if they were moving in the air. But as a matter of fact, the electrodes must travel through the liquid and the resistance which the latter offers to this travel is proportional to the second, if not to a higher, power of the velocity. This resistance may be very appreciably reduced by proper design of the moving parts and this is done of course as far as feasible; but the point is that a certain amount of "dashpot action" should be left in the regulator as otherwise a worse trouble will develop, namely, the hunting or "overshooting" of the mechanism. In other words, the resistance of the liquid will be and should always be present in any slip regulator, regardless of the make or details of design. This feature inherently prevents this apparatus from following rapid and violent fluctuations of load, as take place in steel mills, while its application is entirely satisfactory when the load varies more smoothly.

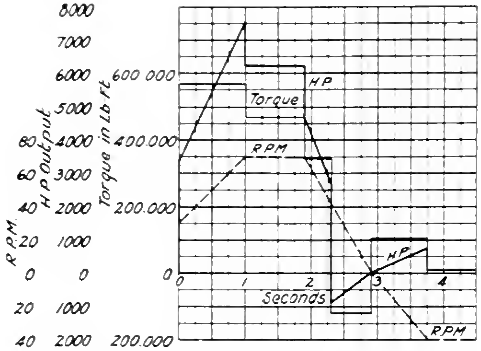

Fig. 20. Elementary Duty Cycle of a Reversing Mill; the Horse Power Curve shows that the load builds up gradually, which fact assists the slip regulator to equalize the load

For instance, in mine hoist practice the fastest hoist does not make more than three trips in one minute; this means that the slip regulator has 20 seconds in which to move the electrodes apart and then to bring them together. For such service the slip regulators are unexcelled, as witnessed by the graphic record, Fig. 17 But in steel mills the load may come on and go off not once, but a dozen times during a period of 20 seconds and it is impossible to expect the same responsiveness from the slip regulator. The perfectly straight line *AB* (Fig. 18) is never encountered or approached in steel mill practice.

In several articles and papers written on this subject graphic records were reproduced showing how much better the performance of the liquid slip regulators is in steel mill practice than the notching-back control, in the sense of reducing the maximum power demand. Unfortunately, the authors of these papers do not always state what was the minimum resistance of the slip regulators used during the tests. It is obvious that by making this resistance high (weaken the solution of the electrolyte) the peaks are reduced even though the slip regulator may not operate as such; this merely corresponds to a large permanent resistance which, as we know, is very effective not only in reducing the peaks but also in reducing the average rolling speed and in boosting the secondary losses. It is recommended that when examining such graphic records that we should also examine the corresponding charts recording the mill speed.

The reversing mills comprise a class in themselves. These mills, driven by direct-current motors are furnished with power from a special motor-generator set; the set is driven by a slip-ring induction motor, and is equipped with a heavy flywheel mounted on its shaft. The line input is equalized by adjusting the secondary resistance of the induction motor which enables the flywheel to play its part. A good general view of such a reversing drive is given in Fig. 19. There is, however, a very definite difference between the power requirements of a reversing mill and those of a non-reversing one. When a piece of metal of a uniform cross-section passes through the rolls, the torque required by the mill to deform the metal is the same at the beginning as at the end of the pass (neglecting the effect of the cooling during one pass). The non-reversing mills are running at constant speed and therefore not only the torque but also the total horse power requirements of the mill rises instantly to the full value at the instant the steel enters the rolls. This explains why such mill duty cycles are represented by rectangular diagrams. In the reversing mills the entering speed is always less than the rolling speed; thus while the rolling torque requirements remain the same, the horse power demand for rolling rises gradually with the increase of mill speed while metal is in the rolls. Fig. 20 shows how the horse power load builds up gradually during the first part of the pass. This character of the load reflects directly and favorably on the slip regulator, as the latter has a better chance to adjust itself to the change of the load.

There is another factor assisting the slip regulators in such cases:

The first cost of reversing mill equipments is considerably higher than for induction motor drives; the cost of the flywheel with bearings is a much smaller part of the whole cost in the former case, and it is more commercially feasible to build a flywheel of a larger capacity for mounting on the motor-generator set than for mounting on the drive itself. For instance, a 2500-h.p. reversing drive has a flywheel with 130,000 h.p. sec. total stored energy, whereas one of the largest sheared plate mills, driven by a 5000-h.p. motor has a wheel of only 63,500 h.p. sec. The larger the capacity of the flywheel the more is the load equalization obtained on the permanent (minimum) part of the slip regulator resistance, and the easier becomes the duty of the electrode mechanism.

Summing up, the load equalization as encountered in the reversing mills may be more readily solved by the slip regulator than it may be in other steel mill cases. The practice fully sustains this conclusion.

We have already pointed out that any of the existing slip regulators have a certain ratio of maximum to minimum resistance which cannot be exceeded; this means that in order to limit the plugging peaks an outside grid resistor should be furnished. If it is not supplied it simply means that the plugging features are not taken care of. To plug the motor with only a slip regulator in the circuit means not only a double peak on the line, but also double voltage on the slip regulator itself.

Comparing the two methods of slip regulation (liquid regulator and magnetic control), other points are to be considered in addition to the operating characteristics of either apparatus.

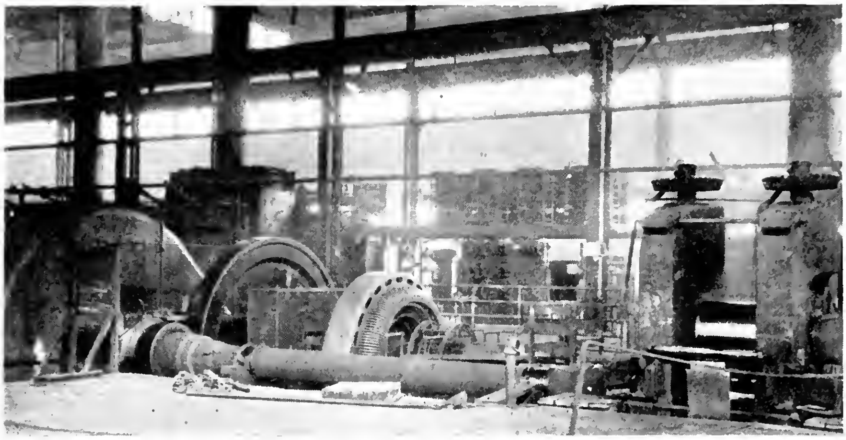

Fig. 21. Typical Location of Flywheel for Geared Mill Drives. The other flywheel identical to the one shown in the picture is mounted on the opposite side of the pinion shaft

The slip regulator is a very simple device in principle; the fact that it eliminates the contactor panel, with the necessary relays and wiring, at times appeals to operators, who think that an inexperienced man will handle it much more easily than the magnetic control. As a matter of fact the contrary is nearer the truth.

There are too many incidental things that may render the slip regulator inoperative unless it is under good care. After regular intervals of time it should be overhauled to clean the dirt accumulating in the tank, etc.; the mill electrician that does this work cannot be expected to reassemble the regulator as thoroughly as it is done at the factory, not having the same facilities. The three electrodes are frequently not re-set in proper alignment and then they may begin to rub against the tubes *B*; the resultant friction makes the regulator absolutely inoperative: if, on heavy overloads, the torque motor overcomes the friction and pulls the electrodes apart, they will oftentimes stay in the raised position even after the load goes off. At the next peak load the motor, having such large secondary resistance, will slow down excessively; the operator then chooses the "easy way," and reduces the counterweights, to make sure that the electrodes shall not move; the purpose of the regulator is annulled, it is used merely as a starting box and as a block of permanent resistance. Many a slip regulator of various makes may be seen around the steel mills in such inoperative condition.

By installing a slip regulator too much reliance is put on the ability of the operator to keep it in good shape. In large and expensive installations, like reversing mills, a good experienced electrician is usually available and it is reasonable to expect that the slip regulator will receive the necessary care. But less elaborate equipments should be made fool-proof; a well made magnetic control, once installed, will work for years without much attention, except renewal of the contactor tips. If any fault develops in the control, it may readily be located and corrected, because all parts are accessible; repairs, if any, may be made in a fraction of the time required for overhauling of the slip regulator.

Of the slip regulators and magnetic-control either one may be made as good and as efficient in its own class as the present engineering art permits. The problem is not which of the two devices is better, but which is more suited for the particular application.

Direct-current Drives

In exceptional cases, when direct current motors are used for driving non-reversing mills equipped with flywheels, the required speed regulation is accomplished very simply and economically.

The motor is furnished with a compound wound field so proportioned that the speed will drop with the load to the amount necessary for making use of the stored energy of the flywheel. No control devices are needed to take care of this performance.

There are no electrical losses incidental to the flywheel operation, like the secondary losses in the case of induction motor drives.

Assuming that the drop in speed is directly proportional to the load the calculations may be made in the same general manner as was done for the induction motors.

Mechanical Arrangement

When a mill is driven by a direct-connected electric motor, the flywheel is naturally mounted on the same shaft. In case of a geared or belted drive the question may rise as to what is the best location for the flywheel: on the low speed mill shaft or on the high speed motor shaft.

It is quite evident that with the first arrangement the high load peaks will be absorbed by the flywheel and they will not be therefore transmitted through the gears. This makes the gear service easier and sometimes a smaller and less expensive gear unit may be used.

However, the same flywheel will have four times greater capacity if its speed (in r.p.m.) is doubled; for the same capacity the wheel designed for high speed shaft mounting will have smaller weight.

Low speed wheels are usually made of cast iron or of cast steel. It is impossible to be certain that such a large casting is of uniform structure; it is not safe to exceed the rim speed of, say, 8000 to 10,000 ft. per minute.

High speed wheels are either made of cast steel or of boiler plates riveted together. In the latter case the uniformity of material is assured; rim speeds may safely go as high as 21,000 ft. per min. or even higher. Fewer pounds per h.p.-sec. stored energy is thus necessary.

This makes the flywheel designed for mounting on the high speed shaft less expensive than the low speed wheel, even though the gear unit should be made stronger and higher in cost. It is very customary to have the high speed flywheel divided in two units each of half capacity and mount them overhung on the high speed pinion shaft, as shown in Fig. 21. With this arrangement the total cost of the bearings is reduced.

The Electron in Chemistry

PART IIB

By Sir Joseph John Thomson

Master of Trinity College, Cambridge, England

The first of this series of lectures was published in our August issue. Last month we published the first part of the second lecture which we conclude in our present number. This, Part IIB, deals with the Disposition of the Electrons in Typical Compounds; Connection Between Chemical Constitution and Chemical Properties; Residual Affinity; Molecular Compounds; Werners Co-ordination Numbers and Electrolytic Dissociation.—Editor.

Disposition of the Electrons in Typical Compounds

Chlorides.—Monochlorides, type HCl. We have here a positive charge outside the octet. The compound has a finite electrostatic moment. The region round the hydrogen atom is comparatively free from electrons, thus molecules of water could be held in stable equilibrium round the hydrogen ion, so that substances with this composition should be hygroscopic.

Bichlorides, type $CaCl_2$. A double positive charge between two octets; the molecule is non-polar. If each of the octets presents a face to the calcium atom, there will be eight electrons on a sphere round this atom; with this configuration there is no room for other molecules. If the chlorine octets swing round so as to present an edge instead of a face to the calcium atom, there will only be four electrons on the layer next to this atom. Thus there would be room for two water molecules if the water octets came edge foremost, or for four if they came point foremost. While if the chlorine octets were also point foremost to the calcium atom, there would be room for six molecules of water. We should expect these chlorides to be very hygroscopic.

An interesting fact about the halides is that we find chlorides such as tungsten hexachloride, WCl_6, and molybdenum pentachloride, $MoCl_5$, sulphur hexafluoride, SF_6, in which there are more than four atoms of chlorine or fluorine combined with one atom of another element. Now if each octet is to present an edge to the central atom, it will furnish two electrons to the layer round the central atom and as the number of electrons in this layer cannot exceed eight, it follows that there cannot be more than four atoms of one kind combined with one of another, a rule to which there are a few exceptions, such as these we are considering. We may explain the existence of these in two ways—one is to suppose that only four of the chlorine atoms are in the inner zone, that the other two are in the outer zone. In this case two chlorine octets carrying a negative charge would be easily detached, so that the compound should be a good electrolyte. The other supposition is that all the chlorine octets are in the inner zone, but only two of them present an edge to the central atom, the other four only presenting a corner. The difference between the two is roughly that, on the first supposition, two chlorine octets are loosely and four firmly held, while on the second two are firmly and four loosely held.

Oxides.—The points previously raised in connection with water apply to the oxides of the univalent elements generally.

Oxides of divalent elements of the type CaO. Here we have the core of the calcium atom outside the oxygen octet. If this octet presents an edge towards the calcium atom, there will be room for three more octets, each presenting an edge, so that we can easily understand why this substance dissolves easily in water. It is not necessary that the octets which go to complete the tale round the calcium atom should be those of water molecules, they may be the octets of other CaO molecules. The fact that the octet of one molecule of CaO can also find its way into the inner zone surrounding other Ca atoms will have a great effect in binding the different molecules together and thereby account for the very high melting points of the oxides. The arrangement in two dimensions when molecules of CaO mutually saturate each other is shown in Fig. 25. The arrow between Ca and O indicates that two electrons have gone from this particular calcium atom to complete the octet round the oxygen atom. The octets are supposed to present their edges to the calcium atom.

Sesquioxides, type B_2O_3. The most symmetrical arrangement for oxides of this type would seem to be one where the three oxygen octets have their centers at the corners of an equivalent triangle, while the cores of the two boron atoms are symmetrically placed on an axis at right angles to this triangle and passing through its center.

Carbonates.—M_2CO_3. We have here three oxygen octets surrounding a central carbon atom. If the inner zone round this atom is to be saturated with electrons, one of the octets must turn a face, while the other two octets present edges, towards the carbon atom. If the octet turning its face to the carbon twists round and turns an edge, there will be room for another octet in the inner zone; thus the molecule can take up water or bind itself to other molecules of the carbonate. There would seem to be the possibility of two isomers, in one both the metal atoms are attached to the octets which present edges to the carbon; in the other, one metal atom is attached to the octet presenting a face and the other to one of those presenting an edge.

Nitrates.—MNO_3. The arrangement is the same as for the carbonates, except that the central atom is nitrogen, with a positive charge of five and not carbon with a charge of four, and there is only one metal atom instead of two to put outside the octets. There is the possibility of two isomers as before.

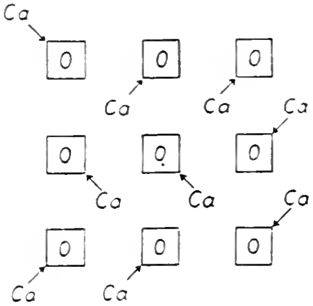

Fig. 25

Sulphates.—M_2SO_4. Here we have four oxygen octets surrounding a central sulphur atom. These must have edges and not faces turned towards this atom. As all the four octets are turned the same way and are similar there will be no isomers.

Perchlorates.—$MClO_4$. The same as the preceding, except that the central atom is chlorine and not sulphur, and there is only one metal atom to place outside the octets.

Sulphites.—M_2SO_3. These from our point of view differ from the carbonates and nitrates because after providing for the electrons to furnish the three oxygen octets, there are still two electrons to provide for. The most symmetrical way would be to arrange them as in Fig. 26, *i.e.*, with one of the M atoms connected directly up with the sulphur and not indirectly through an oxygen octet. This would put the metal atom in the inner zone, from which we should not expect it to be detached in electrolysis; thus if M were hydrogen, this arrangement would correspond to a monobasic acid. H_2SO_3 is, however, dibasic and therefore has probably both the H atoms connected directly with the oxygen and not with the sulphur. In this case we see that there are two electrons which have no direct connection with any but the sulphur atom, and which would be available for attaching to the M_2SO_3 molecule the positive part of any polar molecule or to complete the octet of an oxygen atom and thus form the sulphate.

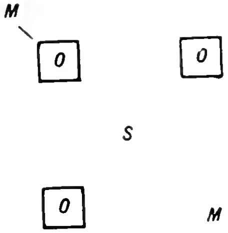

Fig. 26

Chlorates.—$MClO_3$. Here we have the same number of electrons as in the sulphites, but the fact that the chlorates very readily give up oxygen while the sulphites take it up suggests a different grouping of the electrons. The arrangement given in Fig. 27, where one of the oxygen atoms is bound to another oxygen atom and not directly to the chlorine, would represent a molecule which would readily part with oxygen.

This arrangement of two oxygen octets with an edge in common is one that occurs in connection with the molecules of exceptionally intense oxidizing agents, and we have already met with it when considering the form of the molecule of ozone. In hydrogen peroxide H_2O_2 there are two possible forms, one represented by Fig. 28: (*a*) In which both hydrogen atoms are attached to the same

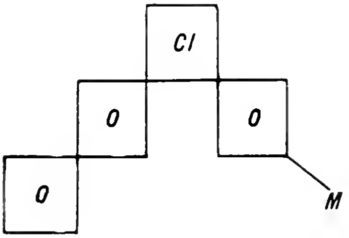

Fig. 27

oxygen octet, and the other (*b*) when one hydrogen atom is attached to one oxygen octet and the other to the other. In both cases we have two oxygen octets connected together by an edge. The first one would possess a finite electrical moment, the second one would not, so that the forms could be distinguished by measuring the specific capacity of H_2O_2 in the gaseous state.

Nitrites.—HNO_2. The nitrites resemble the sulphites in having two electrons which are not in direct connection with any but the central atom. There are two oxygen octets and two electrons *E*, as in Fig. 29. If the hydrogen ion took up the position (H), it would be bound by these electrons, the hydrogen would be in the first zone and the substance would not be an acid. If the hydrogen is attached to one of the oxygen octets, the substance will be an acid, and the two electrons will be free to complete the octet round a neutral atom of oxygen, link it up with the nitrogen, and convert the nitrite into a nitrate.

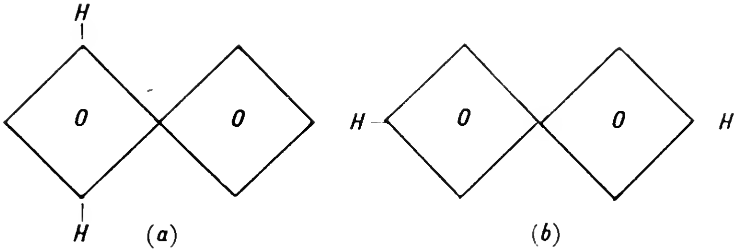

Fig. 28

Connection Between Chemical Constitution and Chemical Properties

If we know the distribution of the electrons and positive charges in a molecule, the behavior of the molecule under specified physical conditions can be calculated from the forces exerted on each other by the electric charges. The exact calculation in most cases would be a process of considerable length, but we can get without an appreciable amount of mathematics a general idea of the nature of the change in properties likely to be produced by changes in the composition of the molecule. The clearest way of illustrating the point in question is to take an example. Methyl alcohol CH_3OH is a substance without any tinge of acid properties; in fact, it is basic, if anything. When, however, two of the hydrogen atoms are replaced by an oxygen one we get formic acid, a substance with pronounced acid properties. We know the general character of the distribution of electrons in the two cases, can we see why the difference in the distribution should make the difference between an acid and a feeble base? We shall suppose that the acid character of a substance containing the hydroxyl radicle OH depends on the ease with which the hydrogen ion H can be detached from the oxygen. We have therefore to see what is the difference between the force on the hydrogen ion in CH_3OH and CH.O.OH. The arrangement of the electrons in methyl alcohol is represented in a general way by the continuous lines in Fig. 30, where for the sake of avoiding confusion in the drawing, the tetrahedral arrangement of the H_3, OH atoms round the central carbon atom has been replaced by an arrangement in one plane. We have the octet round the carbon atom; the size of this does not vary much from one compound to another. We may thus regard this octet as occupying much the same position in the formic acid as in the methyl alcohol. Consider the difference when we replace two of the hydrogens H_2, H_3 by an atom of oxygen. We take away the positive charges H_2H_3, and replace them by a positive charge 6 at the center *S* of the oxygen octet, and four negative electrons at the corners *E*, *F* of the face of this octet. Thus the difference between the forces on the atom H_1 in the hydroxyl radicle in the methyl alcohol and formic acid is the difference between the force exerted by the positive charge 6 at *S*, by the four electrons on the face *EF* of the octet, and that exerted by the two positive charges H_2H_3, which can be represented approximately by a positive charge 2 at *S*. Subtracting this from the charge 6 due to the oxygen, we see that the change due to substituting the oxygen for the two hydrogens can, as far as the forces are concerned, be represented by a plus charge 4 at *S* and a charge on the whole amounting to −4 carried by four electrons at the corners of the square face of the octet. If we replace these by a charge −4 at *G*, the center of the square face, then the force on H_1 in the formic acid molecule will equal the force on H_1 in the molecule of methyl alcohol plus the force due to the doublet with a positive charge 4 at *S* and a negative one −4 at *G*. The effect of the doublet is, as will be seen from the figure, to repel H_1 away from O. It will thus tend to detach H_1 from the molecule, *i.e.*, to make the molecule act like an acid.

As a further example let us consider whether replacing a hydrogen atom in such a compound as formic acid by a chlorine one would increase or diminish the acid properties of the molecule.

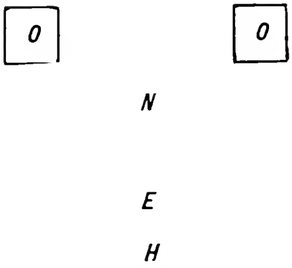

Fig. 29

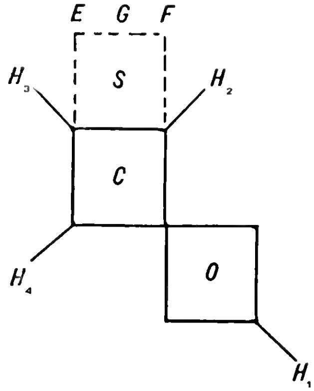

Fig. 30

Suppose that Fig. 31 represents the distribution of the electrons in a molecule of formic acid. If the hydrogen H_4 were replaced by chlorine, the change as far as the electrical forces are concerned will be that the charge +1 at H_4 will be replaced by a charge +7 carried by the chlorine atom, and that six other electrons will be introduced which, with the two along the edge *E*, will make up the octet round the chlorine atom. To calculate the effect of these six electrons, we take the four along the edges *F* and *G;* these are at the corners of a rectangle whose center is at *S*, the center of the chlorine atom. If these electrons act as if they were concentrated at the center of figure *S*, they will have the effect of reducing the positive charge at the center of the chlorine atom from 7 to 3. Now take the two electrons at the edge *L;* these with two of the three charges at the center of the chlorine atom will form an electrical doublet whose moment is $2e \times LS$ with its positive part turned towards the center of the molecule, the remaining positive charge at *S* will represent the positive charge on the hydrogen atom before it was replaced by chlorine. Thus the difference in the forces due to the replacement of hydrogen by chlorine is represented by the electrical doublet $2e.LS$, and this as we see from the figure will tend to drive off the hydrogen in the hydroxyl radicle—thus the substitution of chlorine for hydrogen tends to increase the acidity of the molecule. This is very strikingly shown by monochlor, dichlor and trichlor acetic acids, which are much stronger acids than acetic acid itself.

It follows from the investigation we have just given that if in a hydrocarbon such as CH_4 we substitute for one of the hydrogen atoms *E*, the atom of an electronegative element such as chlorine, the change in the electric forces can be represented by the introduction of an electrostatic doublet at *E* with its axis along CE and the positive part of the doublet turned towards C. The molecule of CH_4 before the substitution of the chlorine atom was non-polar, *i.e.*, the molecule had no electrostatic moment, the substitution of the chlorine for the hydrogen introduces a

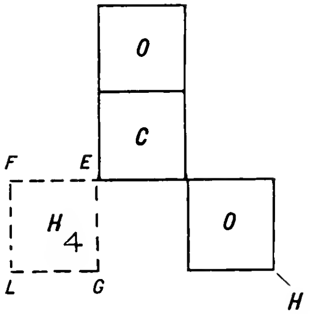

Fig. 31

finite electrostatic moment and thus makes the molecule polar.

The positive part of the doublet at *E* is turned towards *C*, hence the force it produces at *F*, *G*, *H*, the other corners of the tetrahedron whose center is at the carbon atom, will tend to attract negatively and repel positively charged atoms Hence if a molecule of CH_3Cl were placed under such conditions that there were positively and negatively charged atoms in its neighborhood, the concentration of the negative atoms round *F*, *G*, *H* would be greater than it would be for the molecule CH_4 before the hydrogen at *E* had been replaced by the electronegative chlorine. Thus the substitution of the atom of an electronegative element for one of the hydrogen atoms round the carbon will tend to promote the substitution of electronegative atoms for the remaining hydrogen atoms. If two of the hydrogen atoms are replaced by an atom of oxygen, this will for the same reason promote the substitution of electronegative atoms for the other two hydrogen atoms. We have illustrations of this effect in the following examples for which I am indebted to Mr. W. H. Mills.

Ethyl chloride+chlorine (1 molecule) in the liquid state under the influence of ultra-violet light,

$$CH_3.CH_2Cl \rightarrow \underset{\text{70 per cent}}{CH_3.CHCl_2} + \underset{\text{10 per cent}}{CH_2Cl.CH_2Cl}$$

Ethyl bromide heated with bromine in sealed tube,

$$CH_3.CH_2Br \rightarrow CH_3.CHBr_2$$

Chlorine on boiling toluene ($C_6H_5.CH_3$) in sunlight gives successively

$$C_6H_5CH_2Cl,\ C_6H_5CHCl_2,\ C_6H_5CCl_2$$

We see from these examples that there is a tendency for a new hydrogen atom to go into that part of the molecule which is already halogenated.

In the presence of catalysts such as ferric bromide, the halogen atoms in the higher members of the series go to the carbon atom adjacent to the one already brominated.

Another illustration of this effect is the well-known fact that when an organic compound is oxidized the carbon atom attacked is the one which already is attached to oxygen.

I pass on now to consider a problem which I can best explain by stating a particular case. Why is it that in a compound such as methyl alcohol $H_3C.OH$ the only atom of hydrogen which is replaceable by a monovalent metal is the one in the hydroxyl radicle? Or to take another aspect of the same problem, why can the hydrogens in marsh gas not be replaced by the monovalent positive elements, while they can be replaced by the monovalent negative one like Cl, Br, I? Let us consider what are the conditions for the existence of CH_4. We have an octet of electrons round the carbon atoms. The carbon atom which only carries a charge of four units could not by itself keep eight electrons in stable equilibrium. It is enabled to do this by the stabilizing effect of the positive charges which are on the hydrogen atoms. This stabilizing effect will depend on the distance of the positive charge, on the hydrogen from the nearest electron in the octet, a distance which we should expect to be not greatly different from the radius of the hydrogen atom. Consider now the effect of replacing the hydrogen atom by one of an alkali metal; the radius of the atom of the alkali metal is very considerably greater than that of the hydrogen atom. The control over the electron in the metal is much less than that on the electron in the hydrogen atom. This is shown by the fact that the ionizing potential for the hydrogen atom is much greater than that for the metal one, thus we should expect the stabilizing effect of the positive part of the metal atom to be very considerably less than that of the hydrogen atom. Thus while the stabilizing effect of the hydrogen atom may be great enough to make the octet of electrons round the carbon atom stable, that of the metal atom may not be able to do so, in which case the metallic compound could not exist.

In this view the atoms of the monovalent metals are not efficient stabilizers of an octet of electrons, and we should expect that in the compounds they form, the octet should be of a kind that requires little help from the positive charge on the metal atom to make it stable.

Let us consider a few types of the salts formed by these monovalent metals. Let us begin with the chlorides, here we have an octet of electrons round the chlorine atom and the positive charge outside. Now experiments with positive rays show that a neutral chlorine atom, having seven electrons in the outer layer readily takes up a negative charge, *i.e.*, acquires another electron. Thus an octet of electrons round a chlorine atom is stable even without the assistance of an external positive charge, and thus a metal atom outside an octet round a chlorine atom will be a system where the octet is very stable. Hence we should expect that all these alkali metals would, as in fact they do, form chlorides readily. Now let us turn to the hydroxides.

The neutral hydroxyl radicle has seven electrons arranged round the oxygen atom. Now again experiments with positive rays show that the hydroyxl radicle very often occurs with a negative charge and in this state there must be an octet of electrons round the oxygen atom. Thus such an octet with the hydrogen atom outside is stable by itself even without assistance from the positive part of a metallic atom. Thus when it gets this assistance the octet will be very stable, so that we should expect, as in fact is the case, that the hydroxides of the alkali metals would be formed very readily.

Now let us turn to the oxides, here we have an octet round the oxygen atom and the positive part of two metallic atoms outside. As lines corresponding to negatively electrified oxygen atoms are to be seen on nearly every positive-ray photograph, a system of seven electrons round the oxygen atom must be a stable system. In the case of the metallic oxides we have two positive charges to make the system stable when another electron is added. We have seen from the case of hydroxyl that a single hydrogen atom is able to bring about this stability, so that as two metal atoms are available the metal atoms would have to be very inferior to the hydrogen one as stabilizers if the octet were not fairly stable.

Now let us consider why it is that, while we cannot replace by a metal one of the hydrogen atoms directly connected with the carbon atom in a hydrocarbon, we can replace the hydrogen in a hydroxyl group linked up to the carbon. Let us take methyl alcohol as an example, where we may suppose the electrons are arranged as in the diagram. We see that from its position the hydrogen in the hydroxyl group has little to do with the stability of the octet round the carbon atom; it is the stability of that round the oxygen atom with which it is concerned. Now an octet round an oxygen atom is a very different thing as far as stability is concerned from one round a carbon atom. We have seen that seven electrons can be in stable equilibrium round an oxygen atom without any help from systems outside and that a single positively charged hydrogen atom outside is sufficient to make the octet stable. If the hydrogen in the hydroxyl is replaced by a metallic atom, then to keep the octet round the oxygen atom stable we have not only the positive part of the atom of the metal, but also that of the carbon atom with its attached electrons and positive hydrogen atoms. Thus the conditions are much more favorable for the stability of this octet than they are for that round the carbon atom, and thus it may be possible to replace the hydrogen in the hydroxyl but not that in the rest of the atom. The positive rays afford evidence that to make the octet of electrons round the carbon stable in a compound CH_3X, where X is a monovalent element, assistance is required from X. For if it were not, the system got by removing the positive part of X would be stable, but this system is just the radicle CH_3 with a negative charge. Now the line corresponding to this radicle occurs frequently in positive rays, but always with a positive charge; while other radicles, such as OH, are found with negative as well as with positive charges. This is an indication that the stability of the octet round the carbon atom depends upon the presence of X. On the other hand, if the residue after taking away an atom of hydrogen from a hydrocarbon is stable even after receiving a negative charge we should expect that the hydrogen atom might be replaced by an atom of the metal, for the molecule is stable after the hydrogen has been removed and the octet does not depend on the positive charge for its stability. Now on many positive-ray photographs I have observed a line corresponding to a molecule with a negative charge, whose molecular weight is 25, when hydrocarbons were in the discharge tube. The molecular weight indicates that the molecule is C_2H, *i.e.*, acetylene minus an atom of hydrogen, if this is so the hydrogen in acetylene might be replaced by a metal: The compound C_2Cu_2 which is of this type is well known.

Though we have seen the stability of the oxides indicates that the octet round the oxygen atom can be stabilized by the presence outside it of the positive parts of metallic atoms, there are indications that this octet is not so stable as those in the chlorides and hydroxides. The main evidence is that many oxides and sulphides when in the solid state are conductors of electricity, especially at high temperatures, and that, as the researches of Königsberger and Horton show, this conductivity is not electrolytic, but resembles that through metals. There are some chlorides which conduct in the solid state, but as far as I am aware their conductivity is always electrolytic. The conductivity of metals can, as we shall see, be explained as due to electrons which move freely about in certain directions through the solid. So that the non-electrolytic conductivity of these oxides and sulphides indicates that some electrons have got free, *i.e.*, that some of the octets round the oxygen and sulphur atoms have broken up. This breaking up increases very rapidly with the temperature. Another piece of evidence to the same effect is the very intense thermionic emission by oxides such as those of calcium, strontium and barium, an emission which, as Horton has shown, is far more intense than that from the metals themselves at the same temperature. On our view this is due to the breaking up of the octets round the oxygen atoms. The smaller the charge on the neutral atom, the more will the stability of the octet round it depend on the positive charges outside. Thus as nitrogen has only a charge of 5 while oxygen has one of 6, we should expect the octet round nitrogen in a metallic compound to be more easily broken up than that round oxygen in metallic oxides. It would be interesting to test from this point of view the properties of tripotassiumamide, NK_3.

Residual Affinity, Molecular Compounds, Werners Co-ordination Numbers

We have regarded the molecule of a chemical compound as made up of atoms some of which have lost electrons, while others have gained them, so that the former are positively, the latter negatively, electrified; the forces between the electrical charges on the atoms and electrons binding the atoms together in such a way as to form a stable system. The number of electrons which an atom can gain or lose depends upon the nature of the atom. The number it can lose is equal to the number of electrons in the outer layer, and varies from one to eight according as the element belongs to one or other of the Mendeleefian groups; the number it can receive is 8 minus the number in the outer layer.

If the transference of electrons has proceeded to its limit, *i.e.*, if every positively charged atom has received the maximum positive charge of electricity it can acquire and every negatively charged one its maximum charge of negative electricity, there must be simple relations between the number of different kinds of atoms in a neutral molecule. Thus, for example, if we have two kinds of atoms, *e.g.*, calcium and chlorine, since the neutral calcium atom has two electrons in its outer layer and the neutral chloride seven, the calcium atom can lose two electrons while the chlorine atom can only gain one. We see therefore that when the transference of electrons has gone as far as possible, each calcium atom will have given up its electrons to two chlorine atoms neither more nor less and thus for each calcium atom positively charged there must be two chlorine ones with negative charges, thus the composition of the molecule would be represented by the symbol $CaCl_2$. And we can show easily that when the transference of electrons has proceeded to the limit the proportion between the numbers of the various kinds of atoms in the molecule will be the same as that deduced from the ordinary principles of valency.

In such a molecule as $CaCl_2$ the transference of electrons has reached its limit, and as far as this property is concerned the molecule may be regarded as "saturated." Unfortunately there has been a tendency to regard this "saturation" as applying to quite a different thing. Some chemists have supposed not merely that the calcium atom when it had charged two chlorine atoms had exhausted its power of charging up any more atoms negatively, which is true, but they implied, which is not true, that the doubly charged calcium atom cannot by its attraction hold more than two atoms in stable equilibrium. It is important to distinguish between the maximum positive charge the atom can acquire and the maximum number of negatively electrified systems which the maximum charge can hold in stable equilibrium in a single layer around it. The table given in the first chapter shows that when the attractive force between the positive charge and a negative one is represented by $\frac{a}{r^2} = \frac{b}{r^n}$, the number of negative charges which a positive charge can hold in stable equilibrium in a single layer is, when the positive charge does not exceed a limit determined by the value of n, greater than the number of units of positive charge on the central system. This is confirmed by the fact that the positive-ray method reveals the existence of negatively charged atoms, for example, the atoms of hydrogen, carbon, oxygen, chlorine are frequently found to be negatively charged, and a negatively charged atom must have more electrons than the number of units of positive charge. Thus, though a calcium atom could not itself charge negatively more than two chlorine atoms, yet if a third chlorine atom, negatively electrified by some external agent, were brought near the calcium atom, it would hold it in stable equilibrium and form the system $\underset{+2}{\mathrm{Ca}}\ \underset{-}{\mathrm{Cl}}\ \underset{-}{\mathrm{Cl}}\ \underset{-}{\mathrm{Cl}}$. This system would, however, be negatively charged and so could not be expected to remain free under normal conditions; it might, however, be found in electrolytes or charged gases. There may, however, be electrically neutral compounds in which the calcium atom is surrounded by more than two systems. Let us suppose that instead of bringing up a negatively electrified chlorine atom to the $CaCl_2$, we bring up a molecule which possesses considerable electrical moment, *i.e.*, one in which the positive and negative parts are separated by a considerable distance, such for example, as a molecule of water $\underset{+}{H}\ \underset{-}{(OH)}$. The negative end of this would place itself closer to the calcium than the positive one and we should get a system such as that represented in Fig. 32.

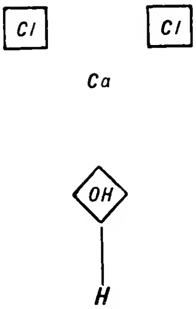

Fig. 32

This system as a whole is electrically neutral and so could exist under normal conditions; it would be held together by forces of just the same type as those which hold the atoms together in $CaCl_2$, yet from the ordinary chemical point of view the latter is a valency compound while the former is not.

It must be noticed, however, that though the number of systems that can exist round the central atom may be greater than the positive charge on that atom, theory indicates that there is a sharp limit to this number, so that the possible compounds of this type would be determined by definite rules.

We can get some information about the number of atoms or molecules which can be grouped in stable equilibrium about a central system *S* by applying the conditions for stability which we have already used when considering the stability of arrangements of electrons in the atom. Let us suppose that the atoms grouped around *S* are the centers of octets of electrons, the electrons in these octets which are nearest to *S* will furnish a layer of electrons round *S* and for stability the number of electrons in this layer must not exceed eight. The number of electrons an octet will supply to this layer will depend upon the orientation of the octet. If *O* is the center of the octet, then if *SO* passes through an electron, *i.e.*, if the octet presents a corner to *S*, it will supply one electron to this layer. If *SO* bisects at right angles the line joining two electrons on the octet, *i.e.*, if the octet presents an edge to *S*, two electrons will be supplied; while if *SO* is at right angles to a face of the octet, *i.e.*, if the octet presents a face to *S*, four electrons will be supplied When all the octets present corners to *S* the maximum number around S will be eight. Considering the exiguous character of this connection between *S* and the octets, we should not expect this arrangement to have any very great stability. If each octet presents an edge to *S*, the maximum number of octets will be four, while if each presents a face to *S*, the maximum number will be two. Thus the number of systems which can be held in stable equilibrium in the first zone round *S*, which following Werner we shall call the coordination number of *S*, may vary from 2 to 8. Werner finds that an appreciable number of elements have a maximum coordination number four, a few have eight, the number for the majority is, however, six, which would correspond to four of the octets presenting a corner, and two an edge to *S*.

The coordination number is never less than the valency and is generally greater. The somewhat vague notion implied by the use of the term "Residual Affinity," which appears frequently in chemical literature, is an attempt to give expression to the facts implied by a difference between the valency and the coordination number. The consequences of this difference are of the first importance. Let us see, for example, how it would facilitate the aggregation of molecules. Let us take as an example formaldehyde COH_2, a substance which is saturated for valency purposes, but is not coordinately saturated. Thus if *A* (Fig. 33) represents a molecule of formaldehyde, then if the coordination number of carbon is four, *A* can hold another negatively electrified oxygen atom in its shell; this may form a part of another formaldehyde molecule *B*, and thus *A* and *B* may be held together in the way indicated in Fig. 33. As *B* is not coordinately satisfied, it may link up with the oxygen from a third molecule *C*; in this way aggregates of the formaldehyde molecule would be formed readily.

We can apply to the union of molecules considerations quite analogous to those we applied to the combination of atoms. Thus, for example, we can picture two molecules of Li Cl joined together by an arrangement like Fig. 34, which is similar to that binding two atoms of lithium together, the electrons in the latter being replaced by negatively electrified atoms in the chloride. Indeed, if the coordination number were always eight, the molecular compounds would run quite parallel with the atomic ones, *e.g.*, the atoms would be arranged in octets in the molecular compounds just as the electrons are arranged in octets in the atomic ones. Since eight is the maximum number of electrons which can be arranged in one layer round a central atom, eight is the coordination number of an atom with respect to electrons; hence when the coordination number in molecular compounds is eight, we see that the molecular compounds will run parallel to the atomic ones. Let us apply this result to a particular case. We saw that when the atoms of an element contain few electrons, so few that these are not sufficient in a diatomic molecule to make up the total of eight, the molecules have a great attraction for each other, so that the element under normal conditions is in the solid state, *e.g.*, Li, Be, Bo, C. When, however, there are sufficient electrons in the atom for the atoms in a diatomic molecule to make up, by sharing electrons, one or more octets, the molecules have but little attraction for each other, and the element is gaseous, *e.g.*, N_2, O_2, F_2, Ne. Considerations of exactly the same character will apply to the molecular compounds formed, for example, by the chlorides. A chloride like NaCl, which contains only one chlorine atom, is analogous to an atom containing only one electron; a chloride like $BeCl_2$, which contains two chlorine atoms to an atom containing two electrons and so on. The molecules formed by atoms which contain less than five electrons exert great attractions on each other and condense into the solid state, while those containing five or more electrons are much more volatile and for the elements in the first period are gaseous. The result we have just obtained shows that we may apply to the chlorides the same reasoning as we applied to the atoms. Hence we should expect those chlorides which contain only a small number of chlorine atoms to be solids; while those containing more than a certain number of chlorine atoms should be much more volatile. The following table of the boiling points of the different chlorides and fluorides shows that this is the case to a very marked extent.

The number of halogen atoms corresponding to a volatile or non-volatile substance will depend upon the coordination number of the element with which the halogen atoms are combined. The smaller the coordination number of the element, the smaller the number of chlorine atoms required to make the chloride volatile As the coordination number varies from element to element, the connection between volatility and the number of chlorine atoms cannot be expected to be as clear cut as that between the volatility of an element and the number of electrons in the atom, when the coordination number of an atom with respect to an electron is always eight. The non-volatility of some of the chlorides such as WCl_5, WCl_6 is, I think, due to the chlorine atoms being in two layers, so that the number in the outer layer, which determines the volatility, is less than the number of chlorine atoms in the compound.

Compounds Containing One Halogen Atom

Name	Formula	Melting Point	Boiling Point
Sodium chloride	NaCl	776	
Silver chloride	AgCl	450	
Sodium fluoride	NaF	above 902	
Compounds Containing Two Halogen Atoms			
Calcium chloride	$CaCl_2$	720	
Magnesium chloride	$MgCl_2$	708	
Strontium fluoride	SrF_2	above 902	
Calcium fluoride	CaF_2	above 902	
Stannous chloride	$SnCl_2$	250	620
Compounds Containing Three Halogen Atoms			
Antimony trichloride	$SbCl_3$	73	223
Bismuth trichloride	$BcCl_3$	230	430
Boron trichloride	BCl_3	liquid	18
Compounds Containing Four Halogen Atoms			
Silicon tetrachloride	$SiCl_4$	liquid	50
Stannic chloride	$SnCl_4$	liquid	114
Titanium tetrachloride	$TiCl_4$	liquid	135
Silicon tetrafluoride	SiF_4	gas	
Compounds Containing Five Halogen Atoms			
Antimony pentachloride	$SbCl_5$	gas	
Molybdenum pentachloride	$MoCl_5$	194	268
Tungsten pentachloride	WCl_5	248	278
Compounds Containing Six Halogen Atoms			
Sulphur hexafluoride	SF_6	gas	
Tungsten hexachloride	WCl_6	275	346

Another example of the analogy in physical properties for similar proportions between the number of electrons in the atom and the number of chlorine atoms in a chloride is afforded by the consideration of the electrical properties of the elements and of chemical compounds.

When there are less than four electrons in the outer layer of an atom of an element, the element is a metal and a good conductor of electricity, the conductivity arising from the movement of the electrons; when there are more than four electrons in the outer layer the element is a bad conductor of electricity. The electrical conductivity of fused chlorides may be compared with that of the metals, the negatively electrified chlorine atoms taking the place of the electrons and making the conduction electrolytic. Chlorides containing a small number of chlorine atoms are good conductors when fused, while the higher chlorides like $SnCl_4$, CCl_4 insulate, although they are in the liquid state.

The thermionic properties of metals find, too, a parallel in those of the chlorides. A metal contains lattices of positively electrified atoms and electrons, the solid chlorides, lattices of the atoms of the metal and of negatively electrified chlorine atoms, and the work required to eject a chlorine atom from the salt would be of the same order as that required to eject an electron from the metal. Again, the proportion between the number of atoms and electrons in the metal would be the same as that between the number of metal atoms and of chlorine atoms in its chloride. Hence we should expect from thermodynamic considerations that at temperatures at which the thermionic emission of electrons from the metal is considerable, there should be an emission of negatively electrified chlorine atoms from the salt. Such an emission does in fact take place.[16] When salts are first heated considerable currents are carried by the chlorine atoms and no electrons can be detected. The effects produced by prolonged heating are very complicated, more so even than those occurring on the emission of electrons from hot metals. This is what we might expect, as the tearing away of the chlorine atoms would produce a more fundamental change in the surface than the emission of electrons from a metal. After prolonged heating electrons, as well as chlorine atoms, are given off, suggesting that the tearing away of the chlorine atoms has produced an excess of metal atoms at the surface.

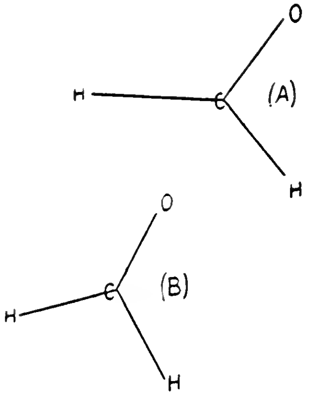

Fig. 33

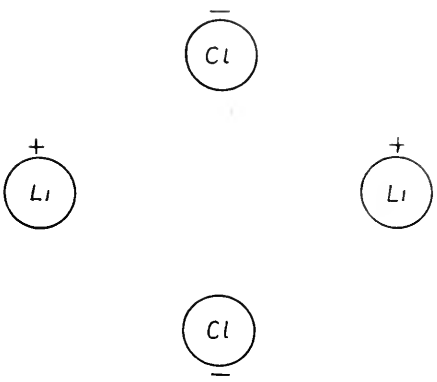

Fig. 34

When the coordination numbers of the metals occurring in double salts are not all equal, the arrangement of the electronegative atoms round the atom of the metal will not be in octets, but one which provides a layer of negative atoms round each atom equal to the coordination number of that atom.

Before leaving the consideration of the coordination number we must raise the question whether a doubly charged atom like oxygen ought to count as two towards the coordination number as it does towards the valency. If we take the view before discussed, the oxygen atom for coordination purposes ought to count as one and not as two. On that view the limits to the coordination number depend on the octets round the central atom. An octet with a double charge, such as that associated with an oxygen ion, can be orientated so as not to bring more electrons into the layer next the central atom than an octet with a single charge like that associated with a chlorine ion, thus the oxygen need not count for more than the chlorine.

Electrolytic Dissociation

When the coordination number of the central atom is greater than its valency, the

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[16] Richardson, "Emission of Electricity from Hot Bodies."

molecule can combine with polar molecules such as H_2O, NH_3 to form new compounds in which the atoms in the original molecule are driven further apart, and are therefore able to rearrange themselves with the expenditure of much less energy than would have been necessary if these compounds had not been formed. Positively and negatively charged atoms may in this way be thrust so far apart and the connection between them made so slight that they move in opposite directions under the action of an electric field, and are thus resolved into ions

This is well illustrated by the well-known example given by Werner of the ammoniates of platinic chloride. If the coordination number of platinum is six, then in $PtCl_4$ there is room for two polar molecules in the first layer round the platinum atom without that layer becoming unstable. The chlorine atoms are in direct connection with a platinum atom and so cannot be detached easily from it. Thus the compound $PtCl_4(NH_3)_2$ is not an electrolyte. If, however, more molecules of NH_3 are added, since 6 is the maximum number of constituents which can be in one layer round the positive charge, the constituents in the inner layer must break up into two groups, one group forming a layer of six next the platinum, the remainder forming an outer layer at some distance from the inner one. The process is very closely analogous to that described in Part I when new layers of electrons were formed when the number of electrons in the atom exceeds the number which can be held in stable equilibrium in one layer by the central positive charge.

Thus if four molecules of ammonia are added to the platinic chloride, there must be two constituents in the outer layer; if these are chlorine atoms carrying a negative charge they will be easily detached and form negative chlorine atoms and the compound will be, as Werner showed it is, an electrolyte, with ions $\underset{+}{PtCl_2(NH_3)_2}$ and $\underset{-}{Cl}$ $\underset{-}{Cl}$. The work required to separate the ions comes from the loss of potential energy due to the approach of the polar molecules to the central system, and not from thermal agitation. The reasons in favor of this view of electrolytic dissociation are in my opinion very strong. I have already pointed out that to ionize a molecule isolated from other molecules would require an amount of energy comparable with the "ionizing potential" of one of its atoms, a quantity varying from one element to another, but comparable with 10 volts. As the average kinetic energy of a molecule at 0° C. due to thermal agitation is, when measured on the same scale, only about 1/30 of a volt, it will be seen that there is little likelihood of the ionization being due to thermal agitation.

On this view of electrolytic dissociation the ions in the solution are not simple atoms or radicles, but combinations of these with polar molecules. These molecules not only dissociate the original molecule, but after dissociation they tend to keep the ions apart. They surround the charge on the central atom with an oppositely charged layer and thus diminish its attraction on other systems. Thus, for example, in an aqueous solution of $CaCl_2$ the positively electrified part of the calcium atom would have next to it the negative ends of polar water molecules, and the attraction between it and an oppositely charged chlorine atom would be diminished. The researches of Mr. Washburn furnish direct experimental evidence of the hydration of ions.[17]

(To be Continued)

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[17] *Technology Quarterly*, *21*, p. 288 (1908).

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alloys, Magnetic

Permalloy, A New Magnetic Material of Very High Permeability. Arnold, H. D. and Elmen, G. W.
Bell System Tech. Jour., July, 1923; v. 2, pp. 101-111.
(Describes the properties of a new alloy for electrical work.)

Amplifiers, Vacuum Tube

Experimental Investigations of High-frequency Amplifier Tubes. Bley, A. (In German.)
Arch. für Elek., May 5, 1923; v. 12, pp. 124-143.
(Considers the various factors that influence the performance of high-frequency tubes.)

Electric Conductors

Reducing Substation Cost and Insulator Hazard by Steel Buses.
Elec. Wld., July 21, 1923; v. 82, pp. 131-132.

Electric Distribution

Rural Distribution Systems. Lang, A. G.
Bul. of Hyd. Pr. Comm. of Ont., July, 1923; v. 10, pp. 238-243.
(Includes methods of overhead and underground construction as used by the Hydro-electric Power Commission of Ontario.)

The Earthed Return.
Bul. of Hyd. Pr. Comm. of Ont., July, 1923; v. 10, pp. 244-247.
(Experiences of the Hydroelectric Power Commission of Ontario and others in the use of the earth as a return circuit for rural lines.)

Electric Heating, Industrial

Electric Heating of Finishing Rolls of Sheet and Tin Mills. Fox, Gordon.
Assoc. Ir. & St. Elec. Engrs., July, 1923; v. 5, pp. 253-268.

Electric Transformers

Air Cooling of the Tanks of Oil Transformers. Rebora, Gino. (In Italian.)
Elettrotecnica, June 25, 1923; v. 10, pp. 406-411.
(Gives two approximate formulas, derived from a series of 16 tests, for calculating the heat transfer from tank to atmosphere.)

Polyphase Transformer Connections. Gooding, R. F.
Power, July 24, 1923; v. 58, pp. 134-136.

Transformer Designing. Baker, C. W.
Bul. of Hyd. Pr. Comm. of Ont., July, 1923; v. 10, pp. 199-209.
(An account of the general principles involved in practical design of transformers.)

Electric Transmission Lines

Viewpoints for Comparison of High-tension D-c. and A-c. Power Transmission. Scherbius, A. (In German.)
Elek. Zeit., July 12, 1923; v. 44, pp. 657-660.
(Discusses the possible fields for high-tension d-c. transmission. Compares a-c. and d-c. systems. Treats of the difficulties of d-c. transmission and tells of experiences abroad.)

Electric Waves

Transient Oscillations in Electric Wave-filters. Carson, John R. and Zobel, Otto J.
Bell System Tech. Jour., July, 1923; v. 2, pp. 1-52.
(Theoretical.)

Electric Wire and Wiring

Design of Power Wiring Systems. Shore, W. J.
Elec. Rec., Aug., 1923; v. 34, pp. 69-73.
(Serial.)

Electrical Machinery—Accidents

Plant Breakdowns.
Elec. Rev. (Lond.), July 27, 1923; v. 93, pp. 155-156.
(Reviews the contents of a report by a British insurance company on breakdowns of electrical and other machinery. Serial.)

Electricity—Applications—Agriculture

Electricity in German Agriculture. Petri, August.
Elec. Wld., July 21, 1923; v. 82, pp. 123-127.
(Illustrates and describes methods and apparatus.)

Electricity—Applications—Valves

Sectionalization and Remote Control of High Pressure Steam Lines. Dean, Peter Payne.
Mech. Engng., Aug., 1923; v. 45, pp. 483-487.
(Deals with remote control by electric motor or steam piston.)

Feed Water Heaters

Economy Effected by Feed Water Heating. Bell, G. G.
Power Pl. Engng., Aug. 1, 1923; v. 27, pp. 777-781.
(Presents results of studies in a large plant.)

Hydroelectric Plants—Testing

Efficiency Tests Made on 55,000-h.p. Hydroelectric Units. Acres, H. G.
Power, July 24, 1923; v. 58, pp. 137-140.
(Abstract of paper before the A. S. M. E. on hydraulic turbine design. Shows results of tests on equipment at the Queenston Plant of the H. E. P. C.)

Insulation—Testing

Measurement of Insulation Resistance. Warren, T. R.
Elec. Rev. (Lond.), July 27, 1923; v. 93, pp. 151-152.

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Results of Tests on Overhead Line Insulators Withdrawn from Service. (In German.)
Schweiz. Elek. Ver. Bul., June, 1923; v. 14, pp. 338-341.
(Illustrated discussion of tests carried out by the Material Testing Laboratory of the S. E. V. on pin insulators withdrawn from service which started in 1909.)

Tests on 100,000-volt Bushings. Brauer, O. (In German.)
Bergmann Mit., May-June, 1923; v. 1, pp. 47-50.
(Short account of results obtained.)

Oil Fuel

Burning Boiler Oil.
Power, Aug. 7, 1923; v. 58, pp. 209-211.
(The first of a series of four articles. This installment treats of types of burners.)

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Self-starting Synchronous Motor and Its Application for Power-factor Correction and Industrial Drives. Mortensen, S. H.
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Protective Apparatus

Danger Signalling Device for Transformers, Oil Circuit Breakers, etc. Stegemann, F. (In German.)
Siemens-Zeit., June, 1923; v. 3, pp. 268-271.
(Illustrated description of automatic signalling apparatus to indicate dangerous operating conditions.)

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Fading; a New Aspect. Burne, W. R. and Cash, J. A.
Wireless Wld. & Radio Rev., July 21, 1923; v. 12, pp. 510-513.

Interference. Marriott, Robert H.
Inst. Radio Engrs. Proc., Aug., 1923; v. 11, pp. 375-389.
(Causes of and remedies for various kinds of interference. Also estimates the money cost of interference.)

On Super-regeneration. Hulburt, E. O.
Inst. Radio Engrs. Proc., Aug., 1923; v. 11, pp. 391-394.
(Brief mathematical study.)

Radio Extension of the Telephone System to Ships at Sea. Nichols, H. W. and Espenschied, Lloyd.
Bell System Tech. Jour., July, 1923; v. 2, pp. 141-185.
(Also appeared in *Institute of Radio Engineers, Proceedingss*, June, 1923.)

Railroads—Electrification

Electric Railway Construction and Operation in Cuba—I. Geenens, L.
Elec. Rwy. Jour., July 28, 1923; v. 62, pp. 127-132.
(Describes the generating and transmission equipment and the rolling stock. Serial.)

Ship Propulsion, Electric

Latest Diesel Electric Ship.
Elec'n, July 27, 1923; v. 91, pp. 86-87.
(Description of British Thomson-Houston equipment for the United Fruit Company line.)

Recent Developments in the Electric Propulsion of Ships. Rettie, Charles.
Elec'n, July 27, 1923; v. 91, pp. 80-83.

Steam Boilers

German Steam Boiler Designed for 850 Pounds Pressure. Schapira, Bruno.
Power, July 31, 1923; v. 58, pp. 164-166.
(Short description.)

Steam Boilers, Electric

Generation of Steam by Electricity. Falter, Philip H.
Assoc. Ir. & St. Elec. Engrs., July, 1923; v. 5, pp. 231-251.
(Discusses the general technical and economic principles involved, the applications, etc.)

Steam Turbines

Improving the Economy of the Electric Power Plant Operation by Increasing the Pressure, the Superheat and the Thermodynamic Efficiency of the Steam Turbine. Gleichmann, H. (In German.)
Siemens-Zeit., June, 1923; v. 3, pp. 245-250.

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Graphic Analysis of Economy of Developing Water Powers. Kenny, G. R. and Golsan, Page.
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Water Turbines

Modern Hydraulic Turbines of Large Capacity. Acres, H. G.
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(Special reference to refinements in design, increased efficiency, improved test methods, etc.)

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE Editor, JOHN R. HEWETT Associate Editor, E. C. SANDERS

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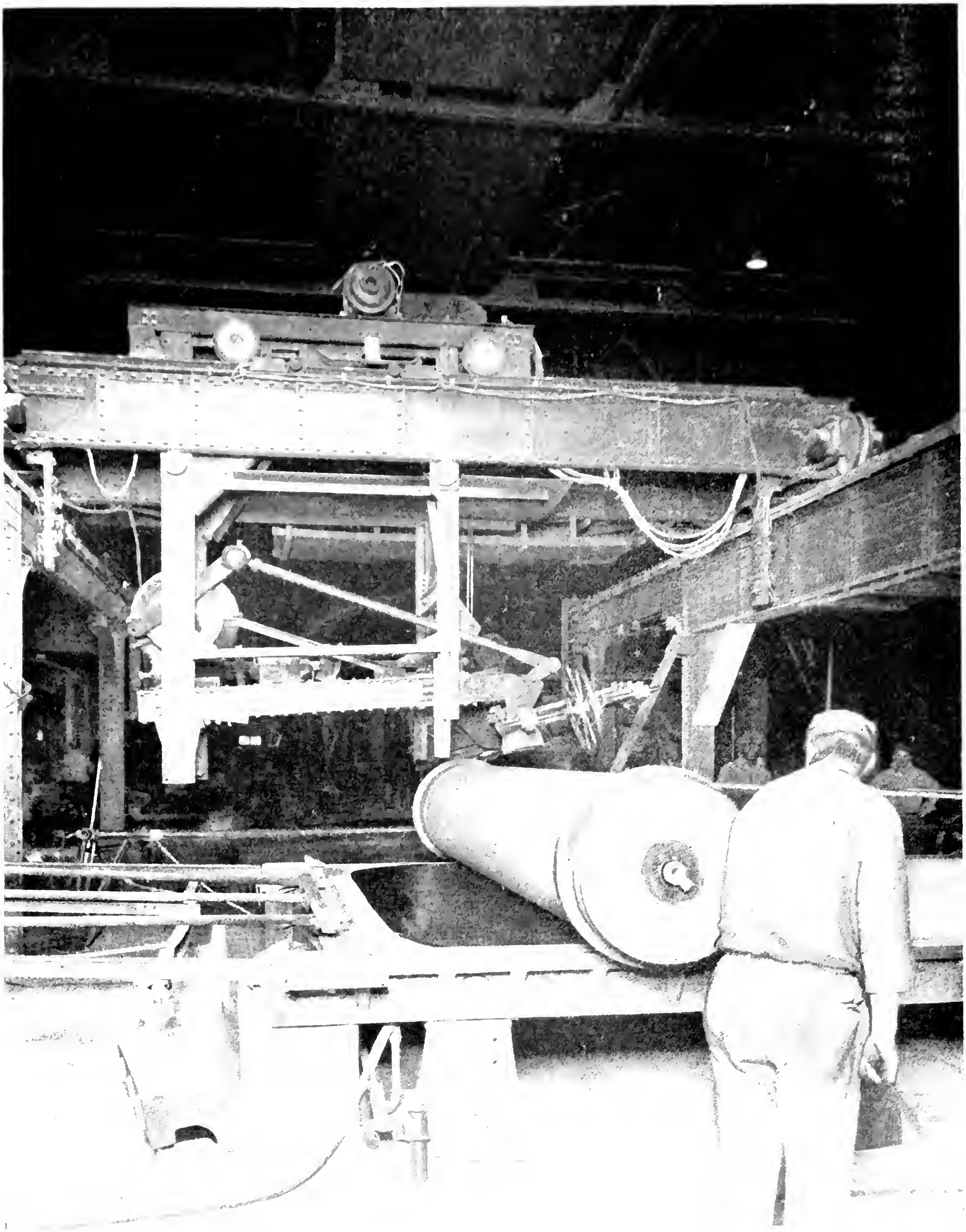

The Casting of Plate Glass. From a pot, manipulated by the teeming crane, molten glass is poured on the casting table in front of the 13-ton roller while this is being rolled to the right. The complete process of manufacture and electricity's part therein is described on page 746.

GENERAL ELECTRIC REVIEW

MUTUAL HELPFULNESS

We are very pleased to be able to publish in this issue an address recently given by Mr. E. W. Rice, Jr. It is descriptive of a visit he and Dr. W. R. Whitney paid to Europe together.

Our pleasure in publishing this address lies largely in the fact that it reads differently from most accounts of foreign visits that we have seen. It is simple observation made by an analytical mind long trained in science, engineering and business. There is no point to be made—nothing to prove or nothing to disapprove—and there is no political or diplomatic slant. Above all it shows a keen grasp of realities and a great appreciation and sympathy for the work of others.

Our reason for calling particular attention to this address is because we have an abiding faith in the good to come from a better understanding between those with mutual interests in different lands. And also we firmly believe in the good to be accomplished by international co-operation in the solution of our problems—be they scientific, engineering, social, or diplomatic.

Such visits by the right types of minds lead to a better understanding, and the world has just gone through, and has not yet recovered from, a ghastly nightmare because *the people* did not understand.

* * * * *

With these thoughts in mind let us get another set of thoughts from a few eloquent but brief paragraphs of Carlyle quoted by John Ruskin in his essay on War.

> What, speaking in quite unofficial language, is the net purport and upshot of war? To my own knowledge, for example, there dwell and toil, in the British village of Dumdrudge, usually some five hundred souls. From these, by certain "natural enemies" of the French, there are successively selected, during the French war, say thirty able-bodied men. Dumdrudge, at her own expense, has suckled and nursed them; she has, not without difficulty and sorrow, fed them up to manhood, and even trained them to crafts, so that one can weave, another build, another hammer, and the weakest can stand under thirty stone avoirdupois. Nevertheless, amid much weeping and swearing, they are selected; all dressed in red; and shipped away, at the public charge, some two thousand miles, or say only to the south of Spain; and fed there till wanted.
>
> And now to that same spot in the south of Spain are thirty similar French artisans, from a French Dumdrudge, in like manner wending; till at length, after infinite effort, the two parties come into actual juxtaposition; and Thirty stands fronting Thirty, each with a gun in his hand. Straightway the word "Fire!" is given, and they blow the souls out of one another, and in place of sixty brisk useful craftsmen, the world has sixty dead carcasses, which it must bury, and anon shed tears for. Had these men any quarrel? Busy as the devil is, not the smallest. They lived far enough apart; were the entirest strangers; nay, in so wide a universe, there was even, unconsciously, by commerce, some mutual helpfulness between them. How then? Simpleton, their governors had fallen out; and instead of shooting one another, had the cunning to make these poor blockheads shoot.
>
> —SARTOR RESARTUS.

* * * * *

Some may think that this is a strange subject for editorial comment in a technical magazine, but our purpose is to be useful. We think it is worthwhile pointing out that the American engineer who can be thrilled by the honor of sitting in Clerk Maxwell's chair and of being shown the room where Davey, Faraday, Maxwell, Tyndall, Thomson, Kelvin, Rutherford and Dewar worked—all men who helped to lay the scientific foundations upon which American industry is built—has understanding; and also, has the type of mind that will appreciate "in so wide a universe, there was even, unconsciously, by commerce, some mutual helpfulness between them."

Mutual helpfulness is the thing that all scientists and engineers in all lands can and should strive for.

Mutual helpfulness should exist between the artisans of all nations.

The League of Nations is not an entire success—the politicians and the diplomats have, at least in part, failed. Can't the engineer help?

The engineering and commercial interests of different countries can and should have mutual interests and they can understand each other better if they visit one another. And if while visiting one another they appreciate the work the other fellow has done, and give of their knowledge as well as take, and confine criticisms to the constructive class, mutual helpfulness will then be so great that in the future it will be harder than in the past to find some poor knave to give the word "Fire" and harder still to find thirty poor fools to obey the order; unless the quarrel is theirs and their fight is for a righteous cause.

We thank Mr. Rice for the seed he has sown.

—J. R. H.

A Visit to Europe

Address by E. W. Rice, Jr.

Honorary Chairman of the Board, General Electric Company

On the occasion of the annual meeting of the engineers of the General Electric Company, which this year took place at Association Island, Mr. E. W. Rice, Jr., read a paper descriptive of his and Dr. Whitney's visit to Europe. Although this paper was primarily meant for the Company's engineers, there is so much of general interest and value in it that we have asked the author for permission to present it to our readers.—Editor.

Dr. Whitney and I sailed from New York on November 21, 1922, on the *Berengaria*, for a visit to Europe, to investigate the condition of scientific research and engineering work. We had neither of us been abroad since the War and were anxious to see what advances had been made which would be of interest and value to the General Electric Company.

In England, we did not learn of startling new engineering developments, but the progress seemed to have continued along well defined lines based upon the experience and practice of the past. There had been a continued increase in the size of generating apparatus, and a good start made towards stations of larger capacity, with large generator units, and designed to generate and sell electricity on a much larger scale than had heretofore prevailed. But in no case did we learn of stations whose power units would seem large judged by common American practice. In the new enterprises and extensions, the generation and distribution was of 50 cycles, alternating current and largely by 30,000-volt, underground cable.

I will say briefly that we were interested in the latest design of B.T-H. rotary converters which were shown to us in operation, and which are so satisfactory in cost and performance as to secure for the B.T-H. Co. the largest share of such business. They were interesting to us as differing in certain details of design, such as starting methods, blowout for commutator, etc., which may be useful to us in America.

There also seemed to be a demand in England for the motor converter. A number have been made and sold by the B.T-H. There is no demand as yet in this country, although the device has been known to us for many years.

The Curtis turbine has been successfully developed in England, under the able engineering leadership of Mr. Samuelson, and has given such a splendid account of itself, even in competition with the Parsons turbine in its own home, that the business has greatly increased and larger facilities for machinery and tools have been found necessary and are being provided.

Some of the latest developments in switching apparatus were of interest, especially the use of an insulating compound for protection of the busbars and the corresponding switches, transformers and instruments, and other switchboard devices and arrangements worked out to co-operate with this new system. The advantages over present methods were said to be a great saving in the space required for substation buildings, etc., as well as greater use of standardized parts. This resulted in great saving to the customer as well as to the manufacturer, although the price of the switchboard apparatus purchased by the customer was naturally much greater than for the air insulated type. I found that our switchboard engineers here were familiar with this new advance. Apparently, however, we have not put out any such apparatus in America. I believe that the advantages of this method of insulation are such that the system will be used to considerable extent in this country, and that we should push our own development as rapidly as possible.

I will say nothing more at present about B.T-H. engineering developments, but will take up our investigations in the research field.

While in London, Dr. Whitney and I, together or separately, saw most of the leading scientific men engaged in electrical or physical research, such as Dr. Donnan, the very able and energetic head of the Chemistry Department at University College, an old friend and brother student of Dr. Whitney's at Leipsic; Professor Aston, of Cavendish Laboratory, Cambridge, whose original work in the discoveries in isotopes have been so fruitful and remarkable. He called upon us on the way to Stockholm where he was to receive the Nobel prize which had been awarded to him. He is fine, modest and enthusiastic; has visited Schenectady, and is therefore personally known to many of our research workers. Incidentally, I believe that he is a good golfer and has a brother who manufactures a very superior type of club. Professor O. W. Richardson, of Kings College Laboratory of Physics, who made early and notable investigations into the laws governing the discharge of electricity through vacua; Sir William Bragg, who is chiefly known through his remarkable work with the X-ray spectra, covering the structure and position of the atoms in crystals; Professor Coker, who is head of the Mechanical Engineering Department at the University College, who spent some time in Schenectady, and whose work in connection with the pictorial illustration of the strains in mechanical work has been made useful to us in many directions. His machine and beautiful methods have been described in the GENERAL ELECTRIC REVIEW.

We also visited the National Physics Laboratory at Bushey Park. (The work of this Government Institution is in many respects similar to the Bureau of Standards in Washington.)

The new Research Laboratory of the General Electric Company, Ltd., at Wembley, is the latest word in this line, having been completed but recently after a careful study by Director Patterson of research laboratories and organizations in other parts of the world, including Schenectady. The buildings and facilities are most excellent. Director Patterson is ambitious to make this laboratory the leader in such work in England. If he is as successful in obtaining a group of scientific workers as he has been in the physical layout, he will be in line to realize his ambition.

On December 11, we took an early train to Cambridge, for a visit to the Cavendish Laboratory, by appointment with its Director, Sir Ernest Rutherford. Rutherford needs no introduction to a group of engineers or scientific men. His investigation into the nature of radium and its disintegration products and alpha ray, his theory of the atom, his brilliant experimental investigations, his broad and fruitful theories and his writings, have all combined to make him justly famous, not only in England, but throughout the world.

Under his leadership there is now gathered at Cambridge a group of talented and earnest workers, many about as well known as himself, such as Professor Aston, C. T. R. Wilson, and others. He is a worthy successor to Sir Joseph Thomson, who, by the way, is now Master of Trinity College, Cambridge, but still retains laboratory rooms at Cavendish.

Neither Whitney nor I will ever forget the two days we spent at Cambridge. Rutherford conducted us about his laboratory, introduced us to his assistants, and showed us a number of his most interesting experiments.

One experiment especially delighted us. C. T. R. Wilson had shown some years ago that by admitting some ionizing particles into a chamber containing air saturated with moisture, and at the same time expanding the air, the track of an alpha particle through the air of the chamber was made visible because of the water drops formed around the ions produced by the particle on its journey. Rutherford showed us such an apparatus, and the ionization produced by the alpha particles was such that the paths of the different alpha particles were clearly defined as separate straight lines radiating from the radium. Some of the lines, after passing straight as an arrow for an inch or more, would bend sharply at an angle. This bending occurred when the alpha particle struck the nucleus of an atom and was deflected. Rutherford repeated the experiment for us a number of times and left no doubt in our minds that we were actually looking at the path of an alpha particle (nucleus of a helium atom) driving with a speed of 20,000 miles or more a second through the gas, and knocking off electrons from the atoms of gas on the way, to finally collide with the nucleus of an atom.

We had read of this experiment many times and had seen the resulting photographs, but the sight of the actual event produced a much more vivid and satisfactory impression of the reality of the phenomenon. Dr. Whitney has arranged to purchase or make one of the Wilson condensation chambers so that we may all have the pleasure of seeing this wonderful phenomenon in our laboratory at Schenectady.

Sir Ernest went with us to call upon Sir Joseph Thomson, Master of Trinity, who invited us to dinner at Trinity Hall and to his rooms in the evening, where we had a most delightful time listening to the entertaining conversation of J. J. Thomson and Rutherford. Sir Joseph, by the way, is a successor to Clerk Maxwell and occupies Maxwell's room at Trinity College. We were both invited to sit in Maxwell's old arm chair, a privilege which we both gladly accepted.

Our thoughts naturally turned to the memory of that genius Maxwell, whose mathematical and theoretical writings elucidated the great Faraday's experimental researches, whose equations demonstrated the identity of light waves and electro-magnetic waves, and therefore that light itself was an electro-magnetic phenomenon. The physical demonstration of this wonderful prophecy had to wait for many years until that incomparable experimenter Hertz made the actual demonstration. We could only wish that Maxwell could have lived to enjoy seeing the fulfilment of his prophecies and to see the great advances in his field made by his successors, Sir Joseph Thomson, Rutherford and others.

We were delighted that J. J. Thomson was able to visit our Research Laboratory at Schenectady at a later date and that Coolidge, Langmuir and others, in the absence of Dr. Whitney, were able to show Sir Joseph matters of interest and to return in some degree the courtesies extended to Whitney and myself while in Cambridge.

We were also gratified that our Directors approved our suggestion, made soon after our return home, to give a small fund to Rutherford for the advance of his scientific investigations. We believe this contribution by the General Electric Company will prove a good investment.

Upon returning to London, we made a visit to Sir James Dewar at the Royal Institution. Dewar met us and conducted us all over the rooms of the Institution. He showed us the library filled with invaluable scientific books and literature, the laboratories of Davy and Faraday, the room where Davy, Faraday, Maxwell, Tyndall, Sir Joseph Thomson, Kelvin, Rutherford, and Dewar himself had lectured, and which Dewar had just refurnished at his own expense—all sacred ground to scientific men. He talked to us of his friend, Lord Kelvin, and of Kamerlingh Onnes. He took us down to his own laboratory and showed us his latest apparatus for experimenting with oil films, about which he lectured a few weeks later before the Royal Institution. The oil was contained in a glass cell and arranged so that the thickness of the soap bubble film could be delicately varied by regulated air pressure. He projected on the screen a picture with all the beautiful tints of the rainbow, which he called "The Dance of the Molecules," and it filled us with longing to know and see more, and to linger in the presence of his strong and fascinating personality.

As we listened to the brilliant conversation of this enthusiastic and witty Scotchman, he was so full of vigor and vitality that it was difficult to realize that he was past 80 years, and easy to believe he would live for many years to advance the cause of science and humanity. We were greatly shocked to hear of his death a few weeks later.

Dewar is chiefly known to the world as one who investigated liquid oxygen, hydrogen, helium and other gases, but particularly as the inventor of the Dewar vacuum flask, which unfortunately is known to the world as the "thermos" bottle. He gave this to the world as a free gift. With much gusto, and in his inimitable manner and brogue, he told us of how his friend Kelvin had called him "an awful fool" because he had not patented his ideas, pointing out that if he had patented the vacuum flask he would easily have made a great fortune. Dewar said he tried Kelvin's plan on his next invention, the use of charcoal for absorbing gases, with the net result that he made an out-of-pocket expenditure of five thousand pounds in lawyers' fees, and had nothing but trouble for his pains. It is a shame that this wonderful invention of the vacuum flask which has done so much for the comfort of millions of people should have yielded nothing to its inventor and that even his name is not connected with it in the public mind. I wish we would all make an effort to speak of the thermos bottle as the Dewar bottle or flask.

From London we went to Paris, and took a few weeks' vacation, during which we incidentally explored the Grimaldi caves on the shore of the Mediterranean near the boundary of France and Italy. Some thirty years ago there were discovered in these caves the remains of prehistoric man along with the remains of the mastodon, the sabre tooth tiger, the cave bear and other extinct animals which lived one or two hundred thousand years ago.

We returned to Paris and resumed our work. We visited the University of Paris, at the Sorbonne, meeting the physicist Fabry of the Institute Optique, Prof. Langevin at the College of France, Professors Abraham, Bloch and DuFraisse at the Physical Department of the University of Paris, Prof. Perrin at the Laboratory of Physics, at the Sorbonne, etc.

We spent some time with Prof. Moureu, head of the Chemical Department in his laboratory at the College of France, and he showed us some interesting new insulating material and chemical substances.

We visited the Gaumont factory and laboratory where we saw talking and colored movies or "cinemas" as they are called in France.

After making several indirect efforts to meet Madame Curie without success, we decided to do it "American Style," took a taxi to the Radium Institute and sent in our cards. We were immediately and most graciously received by Madame Curie. Dr. Whitney led the conversation, as it was in French, but after a short time Madame Curie began, with an apology for her "poor" English, to converse in most excellent idiomatic English, much to my satisfaction, as my understanding of spoken French is painfully limited. For some strange reason I always could understand the French spoken by the Doctor better than that spoken by a Frenchman.

We found Madame Curie an unassuming, intelligent woman, full of enthusiasm for her work, and well posted as to the progress of science in other fields. She is, as you know, the co-discoverer with her husband of radium. She has a fine set of rooms with several assistants at her disposal in the new buildings of the Radium Institute.

The Radium Institute is well provided with clinics and a full line of apparatus for the therapeutic treatment of cancer, etc., by radium as well as by X-ray. This portion of the work is under the direction of Prof. Regaud, biological expert, assisted by a number of young and intelligent scientific workers. Careful investigations are in process and we may hopefully look forward to discoveries which will prove a boon to suffering humanity.

Dr. Whitney found that Madame Curie was desirous of help on X-ray work and Dr. Regaud wished us to assist with new tubes of highest possible voltage, and arrangements were made that this should be done through Mr. Pilon, of the French X-ray Company. In return, the results of experimental work with X-rays at the Institute will be supplied us.

Time will not permit, and I should only weary you if I told of our visits to the Belin laboratory near Paris, where we saw Belin's method of sending copies of photographs, pictures and autographed letters by wireless, or of a visit to the Eiffel Tower wireless station operated by the French Government, containing considerable obsolete apparatus. This is not intended as a criticism, as the condition is probably due to a lack of funds necessary to keep pace with the rapidly advancing technique of the new art.

On our visit to St. Assize, the big wireless transmission station of the French Wireless Company, we were shown apparatus of more modern character, quite similar to that used by our Radio Corporation here in America. We had the pleasure of listening to signals from home—Rocky Point, Long Island.

The French Wireless Company is doing a regular commercial business with the United States, England, Algiers, Syria, Constantinople, the Near East, etc., and works in cooperation with the Radio Corporation of America. Manager Girardeau is young and progressive, and may be trusted to keep his system up-to-date.

We were most favorably impressed by Gaumont, who is the leader in France in the production of moving picture films and apparatus. He has a large factory and laboratory in the suburbs, and operates a large theater in Paris. We visited his factory and laboratory several times and were shown a good colored movie and a good talking movie.

After some weeks in Paris, of which I have given a most fragmentary sketch, we decided to go to Switzerland, partly for a rest and partly to see some things scientific, and also because that was a good way to get to Germany.

After a short holiday at Lake Lugano and Como, Dr. Whitney left me for Germany. While at Lugano we called on C. E. L. Brown, the founder of Brown-Boveri & Co., well known to you gentlemen as one of the pioneers in alternating-current power transmission. He engineered and supplied the apparatus for the famous 3-phase power transmission from Lauffen to Frankfort at the Frankfort exhibition in Germany, in 1891. It was a great pleasure to renew our acquaintance of many years with Brown, who is interested in all things worth while, a good friend to America, and of a most inspiring personality.

Next day we took the electric train for Zurich. We started by riding on the locomotive from Lugano, up the St. Gotthard Pass, and through the famous tunnel. It was a thrilling ride through beautiful scenery. We stopped on the way at Bellinzona and carefully examined the various locomotives in the repair shops of the railroad company located at that place. It is the practice to overhaul each locomotive after about 100,000 kilometers of operation.

The locomotives were made by Brown-Boveri and Oerliken, and have been fully described in considerable detail by the technical press. Our railway engineers are fully familiar with their construction. About 40 locomotives are used on the St. Gotthard Division which runs from Chiasso to Zurich, a total length of about 300 kilometers, and mostly two tracks. All of these locomotives are single-phase, 16⅔ cycles, operating from overhead lines at 15,000 volts with maximum speeds varying from 65 to 90 kilometers an hour and weighing from 90 to 115 tons.

Some 420 kilometers of main line railway have already been electrified, and by 1928 it is expected that 1500 kilometers will be electrified out of a total railway mileage in all Switzerland of 3000 kilometers.

Power for the St. Gotthard Division, above mentioned, is supplied from two hydroelectric stations containing 16⅔-cycle, single-phase apparatus, one located at the south end of the tunnel and the other at the north end. The total installed kilowatts are about 70,000 with a transmission voltage of 60,000 with grounded neutral. Serious telephone and telegraph troubles were avoided by moving the wires away from the railway route, or placing them in lead covered cables buried in the right of way.

At Zurich, we visited the plants of Brown-Boveri, Oerliken, and Escher-Wyss, with a side trip to Winterthur to see the incandescent lamp factory operated by Dr. Remane, who is well known to our incandescent lamp people. We saw at both Brown-Boveri and Oerliken large numbers of electric locomotives of the type already mentioned being manufactured, and they also had an order for freight locomotives for the French Railway system. Brown-Boveri were manufacturing mercury rectifiers on a large scale, and, we were told, had sold at least 200,000 kw. with something like 100,000 kw. in operation.

Dr. Zoelly, head of Escher-Wyss, showed us all through his works and we saw there his latest designs of waterwheel turbines, steam turbines and electric refrigerating apparatus. We were particularly interested in the very well equipped hydraulic laboratory fitted out to test the efficiency of waterwheels under actual operating conditions. We also spent an interesting hour with Prof. Stodola, the great European authority on steam turbines, at the Polytechnic Institute.

At Maastricht, Holland, we attended a Scientific Convention which is held at regular intervals in Holland, to which physicists, chemists, doctors, biologists, etc., from Holland, Belgium, Scandinavia and parts of Germany come together to discuss problems of mutual interest. There we met quite a number of the research engineers of the Philips Lamp Works of Eindhoven, Holland, and also had the pleasure of meeting Dr. Coster, co-discoverer with Hevesey of the element "hafnium." Hafnium is one of the elements, number 72 in the Periodic Series of the elements, whose existence was predicted by Moseley. It is a sort of glorified zirconium. It was rather astonishing to hear Coster state that this hitherto unknown element existed in sufficient quantity in his estimation to represent at least a hundred thousandth part of the crust of the earth. Dr. Nernst, whom we afterward met in Germany, stated that if he had had hafnium the Nernst glower incandescent lamp might still be a commercial illuminant.

At Eindhoven we spent some time visiting Mr. Philips and his research men, and the works and laboratory. Philips is most progressive and has started a research laboratory under the charge of Dr. Holst, assisted by a group of able young scientists. We were most favorably impressed with the character of these men and the quality of their work. We saw under construction a large group of buildings of most excellent design which were to be devoted exclusively to research work.

From Eindhoven we went to Leyden, and there met Kamerleigh Onnes at his Cryogenic Laboratories at the University of Leyden. Onnes is an enthusiastic youngster of 70 or more years, well known as the liquefier of helium and for his investigations into the conductivity of materials at the extraordinarily low temperature of 1 or 2 degrees absolute. In his laboratory he has succeeded in producing temperatures that are estimated to be colder than that of interplanetary space, and has shown that if a current of electricity is merely started even in a lead wire at such low temperatures, it will go on circulating for many hours, because at such low temperatures all conductors of electricity become practically perfect conductors. Onnes speaks of them as "super" conductors.

From Leyden we took the night train for Berlin, arriving there in the morning on time and without any unpleasant adventures.

Our visit to Germany is a story by itself. If I attempted to go into details it would take more time than we have at our disposal.

I may say briefly that we naturally saw first our old friends of the A.E.G., and many others.

Dr. Deutsch, the head of the Allegemeine Co., gave us a luncheon. After a preliminary discussion we were told of the general business situation in Germany, and we obtained the impression that all hands were quite discouraged. Nevertheless the factories seemed to be full and the workmen occupied. So far as we could notice in walking about the shops and streets, the people seemed to be contented, happy and well fed as before the war. We noticed a scarcity of automobiles and yet one could not safely cross Unter den Linden without "watching his step."

We visited the various factories of the A.E.G. and did not notice any great changes over ten years ago in turbines, large generators, motors, and similar lines. We did see some matters of interest as different from our own practice in switchboards and transformers.

We visited the works of Siemens & Halske, A.E.G.'s great German competitor, where we met the Managing Director, his associates, and some of the engineers. We also visited the works of Bergman who makes cables, turbines, motors, locomotives and other lines generally competitive with A.E.G. and to a lesser extent, with Siemens and Halske.

Bergman, as some of you know, was an old associate of Edison, and a friend of ours. He was extremely anxious and proud to show us his factory. We were particularly interested to note that he had large orders for locomotives to be supplied to the State lines in Bavaria. These locomotives were about 2000 h.p. and operated by single-phase, alternating current, 16⅔ cycles. They were in general very similar to the Swiss locomotives already mentioned.

Out of the window of Bergman's office, we saw a super-power line which we were told was operating at 100,000 volts as part of a system for bringing electricity from brown coal mines about 80 miles from Berlin. This installation, which utilizes immense deposits of brown coal which exist in this part of Germany, has been described in the technical press. We were interested to see that these power lines have been put right through what is practically the most populous part of Berlin. This was done during the war, but it is probable they will remain permanently.

The incandescent lamp business in Germany was formerly handled by three large companies,—A.E.G., Siemens & Halske, and the Osram Co. These are now combined into one large company which the three parent companies control. Bergman and some others have been licensed to manufacture drawn tungsten lamps. Dr. Whitney had visited the lamp factories before my arrival, and I did not find time to repeat these visits.

At the time we were in Berlin, the mark was worth about 20,000 to the dollar and had been held fairly stable for some months. A few days after we left it declined to 30,000 to the dollar, and has since been traveling downward until it has reached the present fantastic figure of millions of marks to the dollar. We thought 20,000 was bad enough, as this meant that 1,000 marks were only equal to an American nickel in value.

We were told that the working people, through increases of wages and other means were then obtaining wages equivalent to about 85 per cent of the gold value before the war. The farmers were getting as much or more than before the war; the managing class about 50 per cent, but the professional and scientific and research workers were apparently receiving not much over 10 to 20 per cent, and all the savings invested in mortgages, bonds, etc., of course were valueless. There seemed, therefore, to be a real danger that the scientific and research work of Germany, especially in the Universities and outside of the large industrial corporations was suffering and likely to disappear. This, we all realized, would be a great loss to the world, and Dr. Whitney was especially anxious that something should be done to show our desire to assist pure scientific work.

As a result of meetings with Prof. Nernst, the great German chemist, inventor of the Nernst lamp, and present Director of the Techniches Reichsanstalt, and after conferences with the leading men in the A.E.G. and Siemens-Halske, we arranged to place a small fund at the disposal of Dr. Nernst for specific scientific investigations in which we were interested. The results of this research, if successful, would be useful to the electrical industry in general, and to the General Electric Company as the world's largest manufacturer.

The problem which Dr. Nernst has agreed to undertake is the investigation of the electric phenomena preceding and accompanying the breakdown of insulators. This is a problem on which our own Dr. Steinmetz has been at work, but it is a case where competition is useful.

We also arranged for the assistance of pure electro-physical research in Germany for one year under a Committee consisting of the eminent and well-known scientists Max Planck, Prof. Haber, Drs. Nernst, Laue, and Franke.

The money is to be used for the purchase of apparatus and material, and must not be used to relieve the Government of its duty of properly maintaining any laboratory. It is also to be used for the remuneration of co-workers and assistants. It is not to be used for the solution of problems of direct industrial use, such as specific technical processes.

We visited the Kaiser Wilhelm Institute, under the direction of Dr. Haber. It is a well equipped government institution for research in physics, chemistry and biology, the Reichsanstalt, as mentioned above, and a number of Government wireless laboratories scattered about Berlin, the wireless laboratory of the Telefunken Co., etc.

We came out of Germany by night train which took us directly through the Ruhr territory which had then been occupied by the French for about four months. We could see nothing unusual from the train, although the cities as we passed were more or less deserted, but a large number of people seemed to be working in the fields. The country itself never appeared more beautiful.

Shortly after our trip to Germany we took the steamer from England for home, having been away about five months. Needless to say we were glad to get back to our friends and our regular work.

In conclusion I would say that we found in every country that we visited many men earnestly engaged on researches in chemistry, physics, biology, electronics and allied fields. We were welcomed everywhere in the most friendly spirit and were eagerly shown the latest research. Of course we were equally glad to tell of any similar work in America. There was great satisfaction, even joy, in such mutual exchanges of experiences and opinion.

We were impressed by the willingness of such men to co-operate with American workers in advancing the knowledge of nature's laws. There was no holding back, no reservations, but an evident desire to share new facts, new theories, new knowledge.

While retaining proper pride in the advancements of their brother nationals, the spirit of scientific service seemed to eradicate national prejudices and to forget political boundaries.

Our fresh realization that such men in every country were marshalled together to conquer our great enemies, ignorance and prejudice, inspires us with confidence in a happy and useful future—if only those who are blind may be made to see.

Positive Ion Currents in the Positive Column of the Mercury Arc

By Dr. Irving Langmuir

Negatively charged electrodes in the path of a mercury arc take up a current which is found to be independent of the impressed voltage. Dr. Langmuir, starting with this phenomenon, arrives at a theory which not only explains this fact but which also gives a new conception of the nature of the mercury arc. A short preliminary note describing this theory has just appeared in *Science* and we hope to publish subsequent papers on this subject in the Review.—Editor.

When a mercury arc passes through a tube of uniform diameter, as in the side arms of a mercury rectifier or in a mercury vapor lamp, the tube is filled with a uniform glow whose intensity depends on the current density and the mercury vapor pressure. Practically the whole of the discharge, except in close proximity to the two electrodes, is of the type usually referred to as the positive column.

If an auxiliary electrode of small size is placed in the path of the discharge and connected to an electrometer or potentiometer, it is found that it acquires a definite potential, which in accordance with common practice we may provisionally assume to be that of the gas surrounding it, and, for convenience, we will refer to as zero potential. If the electrode be charged positively to one or two volts, a relatively large current of electrons flows to it from the gas, so that it becomes an anode sharing the current with the main anode. If the electrode be negatively charged, the current to it reverses in direction, but only a relatively small current flows, which increases, in general, slowly, if at all, when the negative voltage is raised to several hundred volts, thus behaving as if it were a saturation current. This current must result from a flow of positive ions to the electrode (out of the gas) or an emission of electrons from the electrode (or from both phenomena). Such electron emission might conceivably be photo-electric emission caused by the intense ultraviolet radiation or it might result from the impact of positive ions against the electrode (delta rays).

Numerous experiments in this laboratory, especially with caesium ions from a genode[*] have proved that positive ions impacting on a surface with velocities up to 300 volts do not cause appreciable electron emission; but the following direct experiments have proved that positive ion bombardment and photo-electric effect cause only very little electron emission from an auxiliary electrode in a mercury arc under the foregoing conditions.

A 5-amp. mercury arc was made to pass through a 1-in. tube from a cathode compartment into a 5-in. spherical glass bulb which was provided with several electrodes, one of these serving as the main anode. Reaching into this bulb was a graphite anode, A, ¼ inch in diameter, surrounded by and entirely enclosed within a cylindrical grid, B, made of 10-mil molybdenum wires with 30-mil spacing. When A and B were connected together and charged negatively, a current of 17 milliamperes flowed, which increased only about 10 per cent when the voltage was changed from 10 to 125.

With B at −20 volts electrons flow readily to A if this electrode is charged positively, a current of an ampere being obtained with only a few volts. But a negative potential of 40 volts or more on B keeps electrons from passing through the grid, so that practically no current flows to A even if several hundred volts (positive) be applied to this electrode. More careful measurement, however, shows that the current to A is not zero. For example, with −60 volts on B and +60 volts on A, a current of 0.094 milliamperes of electrons flowed to A while the current to B was 17 milliamperes: the same as that previously observed to A+B when these were both negative. The current to A is probably due to electrons which are emitted photo-electrically from B and which are then drawn over to A by the strong accelerating field between these electrodes. This conclusion is confirmed by the fact that the current to A remains almost absolutely constant when the voltage on B is changed from −60 to −120, or the voltage on A is changed from +60 to several hundred or even thousands of volts.[†]

More than half of all the electrons emitted from B should pass to A when A is strongly positive. The fact that the current flowing to B was 180 times that flowing to A *proves definitely that the current to negatively charged electrodes is carried by positive ions.*

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[*] Langmuir and Kingdon, *Science*, 57, 58 (1923).

[†] The mercury vapor pressure in this experiment was 0.0025 mm. so that very few ions were formed by collision by electrons passing between electrodes A and B.

At first sight it appears improbable that a positive ion current from an ionized gas should be independent of the voltage. The explanation, however, is very simple. Consider, for example, a uniformly ionized gas in which there are swarms of electrons and ions moving in random directions with velocities corresponding to a fall through a potential of say one volt. Assume that each unit of volume contains equal numbers of positive and negative charges (a condition that must always be approximately fulfilled in the positive column). Then through each square cm. of an imaginary plane surface there flows a certain current of electrons corresponding to a current density I_-. Similarly there is a current density of positive ions which we may denote by I_+. The ratio between I_- and I_+ is thus the same as the ratio of the velocities of the ions, which is the inverse ratio of the square roots of the masses of the charged particles. Since the mercury ion is 200×1848 times heavier than the electron we see that I_- is 608 times as great as I_+.

Instead of an imaginary plane, let us now consider the case of an electrode having a plane surface If this electrode is electrically insulated and is originally at zero potential (same potential as the surrounding gas), it at first takes up 608 times as many electrons as positive ions, and thus becomes more and more negatively charged, until the number of electrons it receives no longer exceeds the number of positive ions. Under the conditions we have assumed, with electrons having a velocity corresponding to 1 volt, the electrode cannot acquire a negative voltage greater than 1 volt, for if it did it could not receive any electrons at all, although it would continue to receive positive ions.

Let us now assume that the plane electrode be charged to a negative potential of 100 volts. Electrons will therefore be prevented from approaching close to the electrode, whereas positive ions will be drawn towards it. There will therefore be a layer of gas near the electrode where there are positive ions, but no electrons, and in this region there will therefore be a positive ion space charge. The outer edge of this *sheath* of ions will have a potential of −1 and the positive ions pass through this outer edge with a velocity corresponding to 2 volts.

Pure electron discharges are well known in which the current is limited by space charge. Between parallel plane electrodes, separated by the distance x, the maximum current density I that can flow with the difference of potential V between the electrodes is given by

$$I = \frac{\sqrt{2}}{9\pi}\sqrt{\frac{e}{m}}\,\frac{V^{3/2}}{x^2} \tag{1}$$

where e is the charge of the electron and m is its mass. If V is expressed in volts, x in centimeters, and I in amperes per square centimeter, this equation becomes

$$I = 2.33\times 10^{-6}\,\frac{V^{3/2}}{x^2} \tag{2}$$

Equation (1) is applicable also to currents carried wholly by positive ions if we substitute in the equation the mass of the positive ion in place of the mass of the electron. With mercury ions, therefore, the currents given by the space charge equation are 608 times smaller than in the case of corresponding electron currents.

We can now calculate the thickness of the sheath of positive ions in case of any given current density and voltage. For example, let us assume that a plane electrode, charged to a negative potential of 10 volts, takes up a positive ion current of 10 milliamperes per cm.² By substituting these values of I and V into the modified equation (2), we find x equals 0.020 cm. On the other hand, if the voltage of the electrode were 100 volts, x would be 0.0035 cm.

The thickness of the sheath with current densities of the order of milliamperes per square centimeter, such as those observed in mercury arcs, is therefore extremely small; in fact, very small compared with the mean free path of the electrons and ions (1 to 5 cm.). Whether the voltage on the electrode is 10 volts or 100 volts, all the electrons that reach the outer edge of the sheath are reflected back into the ionized gas and *all the positive ions that reach this edge of the sheath move towards the electrode and are absorbed by it.* The potential of the electrode has no effect on the potential distribution in the ionized gas beyond the edge of the sheath, and since the displacement of the edge of the sheath by changing the potential from 10 to 100 volts is entirely negligible compared to the dimensions of the discharge tube, it is clear that the number of positive ions that reach the edge of the sheath is also independent of the potential on the electrode.

Thus, the current density of positive ions flowing to a plane electrode measures directly the positive ion current density in the discharge which we have denoted by I_+.

Schottky* has observed currents up to 70 amperes flowing to the iron case of a

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* *Wissenschaftliche Veroeffentlichungen des Siemens-Konzern, II*, p. 252 (1922).

600-amp. mercury arc rectifier, and he found that these currents were absolutely independent of the negative voltage applied to the case. The current densities obtained ranged from 1 to 10 milliamperes per cm.² Schottky attributed these currents to photo-electric effect and has developed a theory of the positive column of the mercury arc totally different from that here described. All of the experimental facts observed by Schottky, however, are in agreement with the present theory of positive ion currents. The remarkable constancy of the currents, which constituted the main reason that Schottky considered them to be photo-electric, is seen, in fact, to follow of necessity if the currents are positive ion currents.

A crucial test of the theory is afforded by the behavior of small, cylindrical electrodes, such as wires, introduced into the path of the discharge. With *plane* electrodes, the increasing thickness of the sheath with increasing voltage does not change the effective area over which the positive ions are collected; but, in the case of small cylindrical electrodes, the increasing thickness of the sheath may cause a very appreciable increase in the effective collecting area.

For example, consider a small wire at a certain negative voltage in an ionized gas. The diameter of the sheath may be twice the diameter of the wire itself, and the collecting area, therefore, is the area of the outside of the sheath, for all positive ions which reach the edge of the sheath must fall into the electrode. If the negative voltage of the wire is increased, the thickness of the sheath increases, and, at a certain voltage, the sheath will have a diameter say three times that of the wire. The current to the wire thus increases with the voltage in proportion to the diameter of the sheath.

This theory can be tested quantitatively, because it is possible to calculate the diameter of the positive ion sheath by means of the space charge equations. The current i of positive mercury ions flowing between concentric cylinders is given by the equation

$$\frac{i}{L} = \frac{14.69 \times 10^{-6}}{608} \quad \frac{V^{3/2}}{r\beta^2} \tag{3}$$

where r is the radius and L the length of the electrode which collects the positive ions, and β is a function of a/r, a being the radius of the sheath. The function β has previously been calculated and tabulated* for the case that the charged particles move from an inner to an outer cylinder. For the inverted case of motion inwards from the outer cylinder, the same method of calculation may be used. Tables of this function β for the inverted case will appear in a forthcoming number of the *Physical Review*. Determinations of the positive ion currents have been made with cylindrical electrodes of several different diameters and with various intensities of ionization in the mercury vapor. Tables I, II, III and IV give a few typical results.

The first column gives the negative voltage on the electrode. The second column contains the observed current in milliamperes. The third column gives the current density at the surface of the electrode as observed. The fourth column gives the value of β which is calculated from equation (3) by substituting in it the values of V (column 1) and i (column 2), together with L, the length of the cylindrical electrode, and r, the radius of the electrode as given at the head of each table.

TABLE I

5-ampere Arc in 5-in. Spherical Bulb. Mercury Vapor Pressure, 0.016 mm. Cylindrical Collecting Electrode: $r = 0.95$ cm.; $L = 5.7$ cm.

V Volts	i Milli-amp.	I Milli-amp. per cm.²	β	a/r	I_+ Milli-amp. per cm.²
16	11.9	0.350	0.0283	1.028	0.340
35	12.5	0.368	0.0497	1.050	0.350
102	13.0	0.382	0.1086	1.110	0.347

TABLE II

4.4-ampere Arc in 5-in. Spherical Bulb. Mercury Vapor Pressure, 0.027 mm. Graphite Collecting Electrode: $r = 0.32$ cm.; $L = 3.2$ cm.

V	i Milli-amp.	I	β	a/r	I_+
3.8	0.60	0.094	0.055	1.056	0.089
13.7	0.65	0.102	0.137	1.139	0.0895
28.6	0.72	0.113	0.226	1.231	0.092
58.5	0.77	0.122	0.374	1.388	0.088
127.2	0.92	0.148	0.614	1.650	0.0897

TABLE III

9-ampere Arc in Tube 3.2 cm. Diameter. Collecting Electrode: $r = 0.0038$ cm.: $L = 1.59$ cm.

V	i Milli-amp.	I	β	a/r	I_+
3	3.00	78.9	0.132	1.134	69.6
8	3.30	86.9	0.264	1.271	68.4
18	3.70	97.3	0.459	1.480	65.7
28	4.20	110.5	0.597	1.631	67.7
53	5.00	131.5	0.884	1.958	67.2
78	5.58	147.0	1.120	2.237	65.7

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* Langmuir, *Physical Review*, 2, 450 (1913) and *Physik. Zeit.*, 15, 348 (1914.)

TABLE IV

Discharge in Tube with Hot Tungsten Cathode. Voltage of Anode, 50; Current to Anode, 0.010 Ampere. Collecting Electrode: r = 0.0063 cm.; L = 1.9 cm. Mercury Vapor Pressure, 0.012 mm.

V	i Micro-amp.	I Milli-amp. per cm.²	β	a/r	I_+
10	36.2	0.483	2.52	4.09	0.118
20	51.0	0.680	3.57	5.65	0.120
30	61.0	0.814	4.42	7.03	0.116
40	67.5	0.900	5.21	8.40	0.107
60	80.0	1.068	6.49	10.8	0.099
80	88.0	1.175	7.67	13.2	0.089
100	96.0	1.280	8.69	15.3	0.084
120	102.0	1.36	9.66	17.5	0.078

Column 5 contains the value of a/r calculated from the function β (column 4) by means of the tables that are to appear in the *Physical Review*. Column 6 gives the positive ion current density at the outside surface of the sheath. This is calculated from the current density on the electrode itself (column 3) by dividing the latter figure by a/r (column 5), since the ratios of the current densities at the outer and inner edges of the sheath must be inversely proportional to the respective radii.

An inspection of these tables shows that the current density varies with the voltage in exactly the manner predicted by the theory. Thus with a large diameter electrode, as in Table I, the variation of i with voltage is slight, since the diameter of the sheath is relatively only slightly greater than that of the electrode. But with small electrodes, the variation in current with voltage may be very considerable, as, for example, in Table IV, where the current increased 17.5-fold when the voltage was raised from 10 to 120.

The variation of the current with the voltage is, moreover, not a question merely of the diameter of the electrode, but depends upon the relation between this diameter and the intensity of the ionization. Thus, if I_+ is very small, the diameter of the sheath will be large, whereas if I_+ is large, the sheath diameter will be smaller. With a cylindrical electrode of given diameter, the variation of the current with voltage is greater when I_+ is small than when I_+ is large. The experimental data are seen to be in agreement with this, as shown by comparison with Tables III and IV.

According to the theory outlined above, the values of I_+ should be independent of the voltage. That this comes out to be the case is conclusive proof of the correctness of the theory.

With wires of such small diameter, or with such low intensities of ionization that a/r is very large (for example, more than about 5) the value of I_+ is found to decrease somewhat with increasing voltage. This variation of I_+ does not indicate any failure of the general theory as outlined, but is, in fact, to be expected, because of assumptions made in the derivation of the function β (a/r). In this derivation it was assumed that the charged particles moving from an outer cylinder to an inner cylinder move exclusively in radial directions. When the ratio between the outer and inner cylinders is not very great, this assumption is well fulfilled under ordinary conditions, but, when the ratio between the diameters is large, even very small tangential velocities of the particles passing through the outer edge of the sheath cause them to form orbits about the small inner cylinder instead of striking it directly. The space charge effects are thus exaggerated and the resulting current becomes less than that calculated on the assumption that the motions are exclusively radial. These effects have been observed experimentally with pure electron discharges, and it is therefore not surprising that the same kind of effect should be observed, and should cause similar discrepancies, in the case of positive ion discharges.

The glass walls of a mercury arc tube should become negatively charged by taking up electrons in exactly the same way as an insulated electrode. All positive ions which move towards the glass walls should therefore strike the walls and be absorbed, and an equal number of electrons should thus pass to the walls to neutralize these positive charges. Since the electron current density I_- must be several hundred times I_+, all but one out of several hundred electrons which move towards the walls must be elastically reflected.

A rather similar state of affairs also exists in the interior of the arc path, for, in general, electrons make elastic collisions with mercury atoms, whereas mercury ions, being of the same mass as mercury atoms, must lose on the average about one quarter of their energy on each collision. Since the mean free path in the ordinary mercury arc tube is comparable with the diameter of the tube, each positive ion must reach the wall of the tube and be absorbed before it has made more than a very few collisions with mercury atoms. Under normal conditions it also follows that very few mercury ions move in a tube in a direction against that of the potential gradient.

The electrons, on the other hand, because of their elastic collisions with the mercury atoms and with the walls, must move in very crooked, or random paths, so that there must be nearly as many electrons moving against the potential gradient as moving with it

Stark* determined the current flowing between two small exploring electrodes in the path of a 3-amp. mercury arc in a tube 2.3 cm. in diameter. The first two columns of the following Table V contain the data giving the current as a function of the voltage, this voltage being measured with respect to a third electrode carrying no current.

TABLE V

3.1-ampere Arc in Tube 2.3 cm. Diameter. Collecting Electrode: r = 0.02 cm.; L = 0.30 cm.

V	i Milli-amp.	I	β	a/r	I_+
4.0	1.35	35.9	0.0463	1.046	34.4
6.0	1.42	37.8	0.0612	1.062	35.6
8.6	1.47	39.1	0.0787	1.079	36.2

It is seen that the currents vary with the voltage in the way expected from this theory, and these data indicate that the value of $\bar{I}_+$ in an ordinary mercury arc is of the order of 35 milliamperes per cm.^{2} Thus, through a given cross-section of the tube, about 20.75 amperes of electrons flow in the direction of the potential gradient, and about 20 amperes in the opposite direction, the observed current of 0.75 amperes per cm ^{2} being the difference between these two.

The presence of such large numbers of electrons with random motions explains why it is that a glow from an arc spreads into a side arm a considerable distance, even if no current flows into the side arm.

The positive ions which strike the glass walls combine with electrons, and must generate on the walls an amount of heat which may be large compared to that carried to the wells by the mercury atoms Günther-Schulze has attempted to calculate the temperature of the mercury vapor in a mercury arc by measuring the heat which flows to the walls. Considering that the ionizing voltage of mercury is 10.4 volts, whereas the energy of thermal agitation at room temperature corresponds to 0.03 volt, it is clear that relatively few positive ions might cause considerable heating of the walls. As a matter of fact, the heating of the walls observed by Günther-Schulze in typical instances corresponds to positive ion current densities of 10–20 milliamperes per cm^2 striking the walls, which is of the same order of magnitude as that observed on negatively charged electrodes in the arc.

Considerations similar to those outlined in this article have led to a new theory of the mechanism of the cathode spot, by which the thickness of the cathode layer is about equal to the mean free path of the electrons in the vapor above the cathode spot and is also determined by positive ion space charge, the positive ion current being of the order of magnitude of half the total current. The potential gradient at the surface of the mercury is thus found to be so great that it is probable that the electrons escape from it by being pulled out of the relatively cold metal by the intense electric field, in accordance with a theory suggested by Schottky. This theory will be described in more detail in a subsequent issue of this magazine.

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* Retschinsky and Schaposchnikoff, *Annalen d. Physik, 18,* 212-251 (1905).

The Don Pedro Project of the Turlock Irrigation District

By R. W. Shoemaker
Superintendent, Electrical Department

The author who was responsible for the electric design and construction and also for the organization of the electrical department describes the most interesting features of the Turlock irrigation district. Data which will be useful to all interested in irrigation projects are given.—Editor.

The Turlock Irrigation District was organized in 1887, under a law which had just been enacted by the California Legislature, giving the people the right to bond their lands for the purpose of developing a water supply for irrigation purposes.

The District comprises 187,000 acres, lying between the Tuolumne and Merced Rivers, and extending from the foothills of the Sierra Nevada mountains to as far west as the San Joaquin River. The soil within this area is what is known as a sandy loam and is very porous, with the result that any rainfall very rapidly drains away, leaving the soil too dry for agricultural purposes. Without irrigation, practically nothing can be raised excepting grain, and even with this crop a failure results unless the rainfall comes within well-defined limits. With irrigation, such crops as alfalfa, beans, corn, fruit, and grapes, grow very luxuriantly.

The first development of the District consisted of the construction of what is known as the La Grange Dam, which is of the overflow type, and is approximately 127 feet high. It is used for the purpose of raising the water in the Tuolumne River high enough to enter a system of canals which have been gradually extended until at the present time there are 250 miles of main canals and 800 miles of secondary canals throughout the District. The flow in the Tuolumne River is extremely

Fig. 1. Don Pedro Dam, North End, Aug. 10, 1922

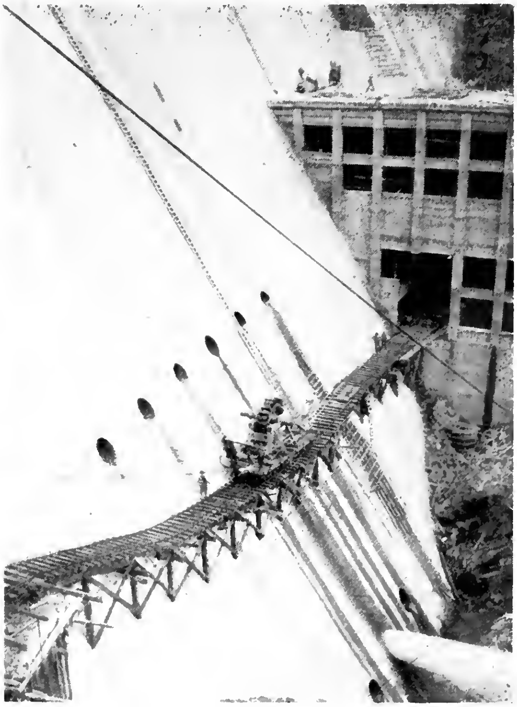

Fig. 2. Generator Rotor on Power House Tramway, Jan. 8, 1923

variable; an average over 20 years showing a maximum of 475,000 acre feet run off in the month of May, falling to 28,000 in September. The average runoff for the month of July is 186,000 acre feet, but this falls to 38,000 in August.

The high water during the early summer is caused by the rapidly melting snow in the mountains and is usually all gone by the end of July. The physical characteristics of the water shed area preclude the retention of moisture to any extent; hence the sudden falling off of the river flow with the melting of the snow.

As the agricultural season in the District extends through September, it is apparent that a need for additional water supply during the months of August and September was soon felt. An attempt was made to overcome this difficulty by constructing a reservoir in the foothills, having a capacity of 48,000 acre feet. With the growth of the District, this storage became inadequate, and it was necessary to look to more satisfactory methods of increasing the water supply to the farms.

Fortunately, there existed in the mountains a short distance above the diversion dam a peculiar formation where two canyons branched out from the main river just above a very narrow gorge in solid rock formation. The early gold miners had noticed this locality, and it had taken the name of one of the early Argonauts and was known as the Don Pedro Dam site. The District had for many years contemplated the construction of a dam at this point for the additional storage of water, but it was not until the year of 1921 that conditions had shaped themselves so that actual construction was begun.

On August 23, 1921, the first concrete was poured in the toe wall of the Don Pedro Dam; the last concrete in the structure being poured March 15, 1923. In this interval, there were placed in the dam 281,000 cubic yards of concrete, and 28,500 cubic yards of rock excavated in the dam site, also 130,000 cubic yards excavated in the spillway. The work of placing the concrete was, of course, interrupted by high water during the high water season of 1921 and 1922, so that not much progress was made until March, 1922. It then became necessary to conduct the work so that the dam would be finished in time for the high water period in 1923.

Fig. 3. Lowering 28-ton Generator Rotor to Power House, Jan. 8, 1923

The capacity of the dam proper is 260,000 acre feet, which can be increased to 289,000 by raising a set of gates in the spillway, increasing the height of the water level 9 ft. The total height of the dam from the river bed is 283 feet; the length at the top 1000 feet, and the length at the base, 75 feet; while the respective thicknesses are 16 feet and 177 feet. The dam is of the solid gravity type, but is also constructed as an arch, with a radius of 674 feet.

With this amount of water in storage at a head varying from 130 to 250 feet, there exists of course an excellent opportunity to develop a considerable amount of power. The District, therefore, constructed a power house

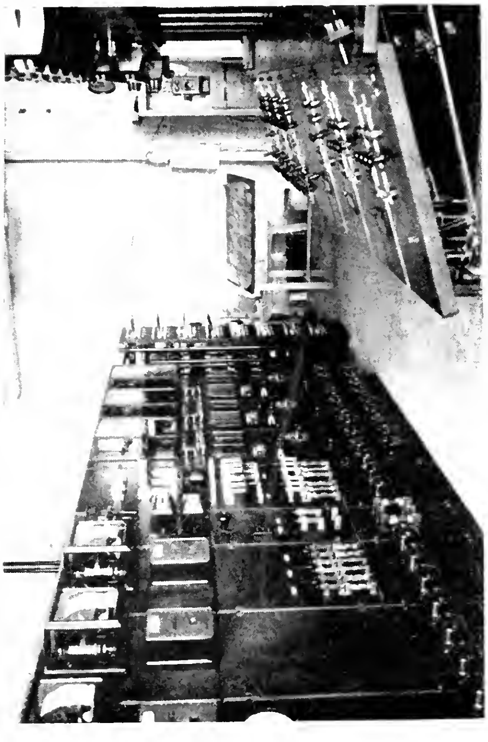

Fig. 4. Detail View of the Switchboard Equipment, also shown in Fig. 6

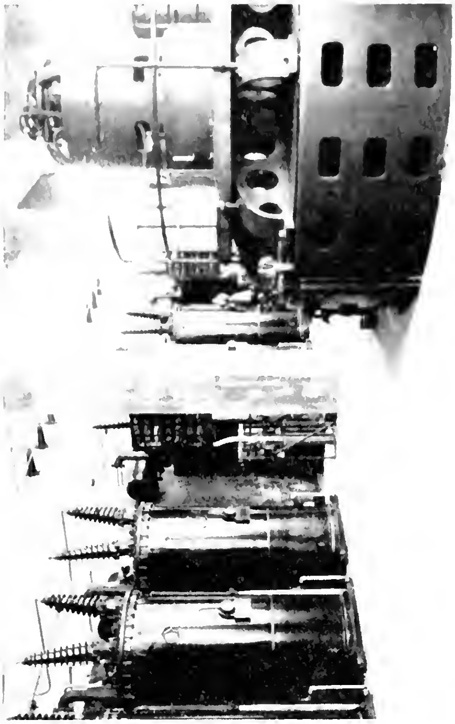

Fig. 5. 5000-kv-a. Waterwheel Generator and Transformers

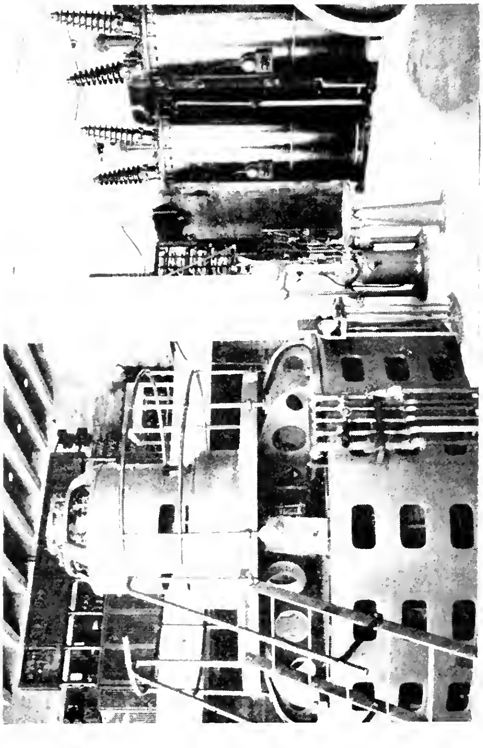

Fig. 6. Switchboards, Transformers and One of the Three Generators

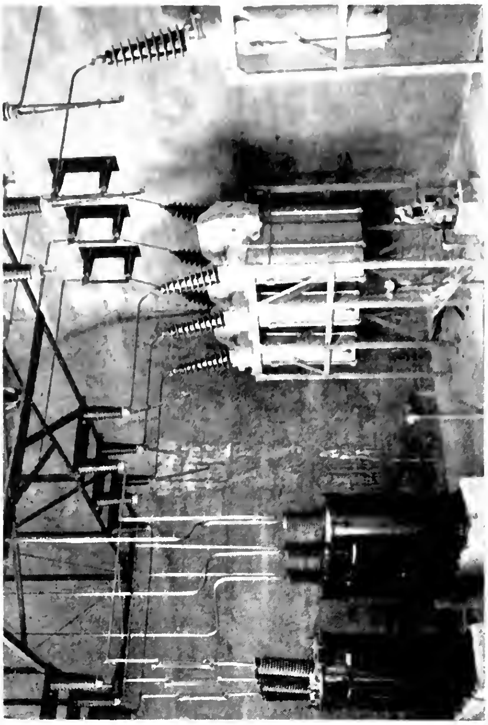

Fig. 7. Oil Circuit Breakers and Instrument Transformers

with an initial installation of three 5000 kv-a. machines of the vertical type, direct connected to turbines designed to operate with a head varying from 100 ft. to 240 ft. These machines are able to generate full capacity with a head of above 160 ft. with an efficiency of not less than 83 per cent throughout the entire range. The greatest efficiency of 90.1 occurs at a head of 120 feet and the minimum efficiency at the maximum head of 240 feet; under which cond tion of course the efficiency is of least importance.

Provision was made in the construction of the dam for the future installation of two more units. The maximum amount of power that could be generated at Don Pedro is somewhere in the neighborhood of 60,000 kw., but this would be available only over a part of the year. The probable maximum economic development will be in the neighborhood of 35,000 kw. It is not possible to estimate accurately what this maximum development will be, owing to the fact that the irrigation requirements, which must be given precedence on the water delivery, are somewhat of an unknown quantity, for the reason that prior to the construction of the dam the farmer had a tendency to use more water on his land than he knew was good for it in an effort to increase the length of the irrigation season. It is probable that the effect of the dam will be to increase the irrigation season without a corresponding increase in acre feet of water applied to the lands.

The amount of water available for power during the low period of the river is of course dependent on how much water is withdrawn from storage between the end of the high water period and the end of the irrigation season.

Furthermore, it will be possible to develop a large pumping load in sections of the district which have an elevation too great to receive the benefits of gravity irrigation, which load will be coincident in time with the demand for water; hence, for these reasons, the ultimate development is, at this time uncertain.

As the laws affecting irrigation districts have been modified so as to permit such districts to go into the generation, distribution and sale of electric power, where such power can be generated in conjunction with their hydraulic development, the people of the Turlock District by an overwhelming popular vote decided to distribute the power to themselves rather than sell it wholesale to the power companies.

As the City of Turlock does not enjoy terminal freight rates, the probability of developing a large manufacturing load is rather remote; so the market for the Don Pedro power seems to lie in the development of the use of electrical energy in the home and on the farms. The most obvious outlet along these lines is, of course, the use of the electric range and water heater.

It would be hard to imagine a more promising field for this development, as the cost of fuel is very high; wood selling for $27.00 a California cord and coal at $18.00 a ton. The climatic conditions are also favorable to this, as the winters are not excessively cold, the thermometer rarely going as low as 32 deg. F., and the summers are quite hot.

The District is therefore proceeding along the lines indicated in developing the use of electrical energy, and in so doing, it has adopted a "Readiness to Serve" system of rates as being the most logical method of encouraging the use of electrical energy under the conditions existing within the District.

It must be borne in mind that the dam was erected and that the cost was justified from the standpoint of water storage and development, and as water must be passed through the dam for from seven to eight months a year, the cost of power within that time can be the only actual cost of operation of the power plant, fixed charges of course included. It is probable that under all conditions, water will have to be wasted through the irrigation outlets, hence the cost to the District of maintaining the consumer during these months will be practically independent of the amount of electrical energy that he uses. The cost of carrying a consumer will be entirely in the cost of transporting the energy to him, and it is for these reasons that the Readiness to Serve method of rate making is the fairest to both parties. To accomplish this, a rate with a relatively high service charge coupled with a relatively low energy charge has been developed to meet the local conditions.

In addition to the use of power for lighting, cooking, etc., there exists within the District a very unique and serious problem, which can be most advantageously solved by the use of pumps using electric power. This is the drainage problem, and is caused by the fact that the continual use of water on the lands of higher elevation in sufficient quantities to meet the agricultural requirements results in the gradual flow of this water down towards the lands of less elevation, with the result that these lands become too wet for satisfactory development. In many areas within the District, this flow has caused the water plane to rise so high that some sections are absolutely unfit for agriculture and have to be withdrawn from the taxable areas, thereby cutting off the revenue of the District at its source. Attempts have been made to meet this problem by the construction of what were known as drainage canals, which were deep canals cut into areas that were becoming flooded; but these ditches did not prove to be an entirely satisfactory solution of the problem.

The District has installed in the affected lands quite a number of turbine pumps, driven by vertical electric motors, which receive their power from the Don Pedro System. Although these pumps have only been in operation a few months, there has been in their localities a marked lowering of the water plane, even to the extent of drying up some small lakes which existed near the location of some of the pumps.

It is contemplated that eventually there will be over one hundred of these pumps, and it is expected that the use of 3500 acres of land will be reclaimed by this method; also, what is more important, that there will be no further increase in lands withdrawn from taxation on account of high water plane. The water pumped from these wells is diverted into the irrigating ditches, where it can be used over again for further irrigation.

It is quite probable, in the future, that many farmers will prefer to pump their water electrically, rather than make use of the free water supplied by the District's canals; for the reason that by having a pump they will be able to have the water exactly when their crops require it. The gravity water is only available at certain periods, as each tract of land must take the water in turn. In this connection, it is interesting to note that from 10 to 20 times as much water can be furnished by pumping electrically as can be supplied through the canals, for the reason that the loss from evaporation and seepage between the dam and the ultimate consumer is in the neighborhood of 50 per cent when supplying water to the land through the canal system. As this is approximately the over-all efficiency between the power plant and the electrically operated pump, the total water supplied is in proportion to the ratio existing between the height the water has to be pumped and the head of the water on the generator turbines.

As the average head at the dam will be in the neighborhood of over two hundred feet, and the average pumping head is between ten and twenty feet, the reason for the above ratios is apparent.

The use of electrically driven pumps would make it unnecessary to devote several thousand acres of land to canals as at present. While it is not probable, however, that the District will ever reach a point where the canals will not be used at least to some extent, yet from the requests for power for pumping that have been received to date, it is apparent that many farmers are going to make use of the more expensive method of electric pumping, which they can use at any time, rather than depending on the ditch water, which can be used only on schedule.

The dam was constructed under the direction of Mr. R. V. Meikle, Chief Engineer of the Turlock Irrigation District, with Mr. A. J. Wiley, of Boise, Idaho, as Consulting Engineer.

Review of the Lamp Report of the National Electric Light Association

By George F. Morrison

Vice-President, General Electric Company

On several previous occasions we have reviewed the Lamp Committee's report of the National Electric Light Association, which is always an interesting document. The review of this year's report shows that we are still progressing rapidly in the direction of standardizing and of giving the customer more light for a dollar.—Editor.

The Lamp Committee of the National Electric Light Association each year, since 1908, has submitted a report to its annual convention containing a great deal of interesting data regarding the developments of electric illuminants during the previous year. The latest report, giving data on the progress in 1922, contains a voluminous amount of statistics on incandescent lamps during the sixteen years, 1907-1922 inclusive.

Total Incandescent Lamp Sales, 1907-1922

In 1907, the total sales of incandescent lamps (excluding miniature lamps) in the United States amounted to about sixty-five million lamps. The tungsten filament lamp had just appeared on the market and the tantalum lamp the previous year, their sales however then being a negligible proportion of the total. In 1922, the total sales were 203 million lamps, over three times that of 1907.

This increase in lamp sales, however, does not fully indicate the growth of the use of light. During the sixteen-year period, the demand for the carbon filament lamp decreased until it is now practically a negligible item and the tungsten filament lamp now constitutes over 98½ per cent of the total demand. The candle-power of the average size of tungsten filament lamp sold in 1922 is nearly four times that of the average carbon filament lamp of 1907, so that the aggregate candle-power of the lamps sold in 1922 is about twelve times that of 1907. This is diagrammatically shown in Fig. 1.

The tantalum lamp never became a large factor and disappeared from the market in 1913 owing to the greatly superior efficiency of the tungsten filament lamp, even though the latter was a comparatively fragile lamp until the introduction of drawn tungsten wire for its filament in 1911. An improved carbon filament lamp, known as the metallized carbon or Gem lamp, was first marketed in 1905. This lamp was largely used by central stations as a free renewal lamp. Its sales increased until it reached a maximum proportion of about half of all the carbon filament lamps sold, then falling off and disappearing from the market in 1918.

Average Watts and Efficiency

The average wattage of the lamps sold decreased slightly during the first six years of the sixteen year period, from about 53 to 47 and then gradually increased to practically 55 in 1922. The decrease was due to the replacement of carbon with tungsten filament lamps of slightly less wattage although of much higher candle-power. The later increase was due to the gradually increasing use of the gas-filled tungsten filament lamps which appeared in 1913, and which could at first be made only in the very high wattage sizes. It is the writer's belief that this shifting in the average wattage does not indicate a similar change in the amount of current used by the average central station consumer. The consumer not only has used a higher average candle-power lamp but has been burning it for longer periods, so that the average sales of current per customer has probably increased appreciably since 1907.

The efficiency of an incandescent lamp used to be expressed in "watts per candle." This term is unfortunate as an increase in efficiency would be indicated by a decrease in watts per candle. Furthermore, the candle-power of a lamp usually meant its "mean horizontal" candle-power, which is the average candle-power a lamp gives in a horizontal plane. The "mean spherical" candle-power, which is the average candle-power a lamp gives in all directions, is a better measure of the total light it gives, because the ratio between the mean horizontal and mean spherical is different in different lamps. This ratio depends on the shape of the filament and is somewhat different for the different sizes of tungsten filament lamps which have ratios very different from that of the carbon lamp.

In order to get away from the incomplete term "candle-power," the term "lumen" was adopted. One mean spherical candle-power is equivalent to practically 12.57 lumens, and the old 16 c-p. lamp gave practically 160 lumens. A corresponding change was made in the term expressing efficiency, a reciprocal expression "lumens per watt" being used, so that an increase in efficiency is shown by an increase in lumens per watt.

The increase in candle-power and watts of the average lamps sold in 1907 and 1922 has already been stated, so the efficiency of these lamps, expressed in the modern term of lumens per watt, has increased from less than 3½ to over 11½, an increase of nearly two hundred and fifty per cent.

Voltage of Lamps

There are several groups of voltages for which tungsten filament lamps are regularly made. In many cases lamps can be had, if desired, for each individual voltage within the range of that group. In addition, lamps are made for use on street series circuits which are rated in amperes instead of volts.

115-volt Group

The most popular voltage is the so-called 115-volt group which covers over 88 per cent of the total demand. Originally lamps were regularly made in this group for each individual voltage between 100 and 130, and a demand for such individual voltage lamps was fostered. This was necessary in the carbon lamp days as it was impossible to predetermine the exact voltage of every carbon lamp made. With the development of the drawn tungsten wire filament in 1911 it became possible to predetermine exactly the voltage of such lamps and a movement was started to eliminate the demand for many of the voltages between 100 and 130 as the use of carbon lamps decreased.

One voltage would, of course, be an ideal situation not only from the lamp manufacturers' standpoint but also from that of the consumer as he would then be able to get better delivery than is possible with a multiplicity of voltages to be supplied. The 115-volt lamp is now considered the standard, but 110- and 120-volt lamps are known as recognized departures from the ideal standard. These three voltages in 1913, when voltage standardization was first started, constituted less than half of the 100-130-volt group. In 1922 they constituted considerably over 90 per cent. This percentage will increase, as the lamp report shows that nearly 97 per cent of the total population in the United States that is served with current is supplied at one of these three voltages, nearly half of which is 115 volts.

The increase in the demand for the standard voltages during the years 1913 to 1922 inclusive is shown in the diagram, Fig. 2. Excluding the present 5 per cent demand for 125-volt lamps, about one-half of the remaining 3½ per cent demand for odd voltages is for the 112-volt lamp. While this is a small percentage of the total, it means, however, that over two million 112-volt lamps were sold in 1922.

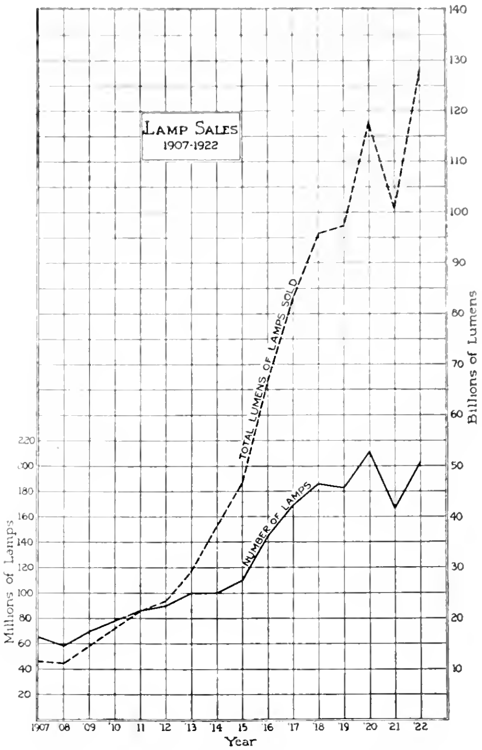

Fig. 1. Incandescent Lamp Sales, 1907-1922

The lamp report again calls attention to the fact that the use of 112-volt lamps should be discouraged. In practically all cases their use is a continuation of the old practice of burning 112-volt lamps on 110-volt circuits. This practice was adopted in the early days of the tungsten filament lamp to compensate in lamp life for the fragility it then had. With the present sturdy drawn wire filament this practice is no longer warranted, as it entails a sacrifice of candle-power, wattage and efficiency.

Other Voltage Groups

The 230-volt group in 1922 constituted 4 per cent of the total. This percentage is less than in former years and indicates that lighting installations on 230-volt circuits, usually power circuits, are being changed over to 115-volt lighting circuits. Such a change is most desirable, as not only are the 115-volt types of lamps more readily available on account of their large demand, but they are lower in price and more efficient than 230-volt lamps. Practically all the demand in the 230-volt group is for the four voltages: 220, 230, 240 and 250.

The 30- and 60-volt groups constitute about 3½ per cent of the total, most of the demand being in the 30-volt group. Lamps of these voltages are generally used in gas-engine driven electric plants for rural homes beyond the reach of central station circuits and for illumination in railroad coaches and Pullman cars that have a storage battery which is usually kept charged by a generator driven by a belt from the car axle.

There is a so-called street railway voltage group which constitutes two per cent of the total lamp demand. These lamps are similar to the 115-volt group, but are designed for series burning, each size of lamp, irrespective of its voltage, being made for a given amperage. They are supplied for use, five in series, on 525, 550, 575, 600, 625 and 650 volts.

The remaining miscellaneous voltage groups cover less than one per cent of the total demand. They include such lamps as 11½-volt sign lamps, which are burned on transformers reducing the 115-volt alternating-current circuit to one-tenth of this pressure, and 275-volt lamps used in mine lighting service.

Street Series Group

About 1½ per cent of the lamps sold are in this group. This does not indicate the proportion of lamps used for street lighting as many lamps of the 115-volt group are used on multiple street lighting circuits.

The standard series circuit for incandescent lamps is 6.6 amperes and probably 70 per cent of the lamps in this group are burned on this circuit. This is because the efficiency of 6.6-ampere lamps of the ordinary sizes is greater than those made for other currents. These 6.6-ampere lamps constitute 60 of the 70 per cent. The high candle-power sizes, which constitute over 10 per cent of the group, are more efficient if made for 20 amperes, so these lamps are usually operated on compensators to permit their use on 6.6-ampere circuits.

The other series lamps are 4 amperes covering 9 per cent, 5½ amperes covering less than 8 per cent and 7½ amperes covering 12 per cent of the demand in the street series group. It should be noted that the so-called 4-, 5½- and 6.6-ampere luminous or magnetite arc rectifier circuits supply a current whose mean effective heating value is different from the figures given. For this reason special lamps are made for use on these circuits, being labeled the nominal amperes of the circuit, but actually made for the heating value of the current. For example, the 4-ampere lamp for General Electric rectifier circuits is actually made for 4.25 amperes though labeled "4 Amp. G.E. Rect." The 4-ampere lamp for use on Westinghouse rectifier circuits is actually made for 4.1 amperes though labeled "4 Amp. West. Rect." In addition, these series lamps for use on rectifier circuits are designed to operate at a poorer efficiency than regular series lamps operated on constant current transformers, in order to compensate for the great surges in current which occur on rectifier circuits. For this reason the vacuum tungsten filament lamp is recommended unless a surge arrester is used, as the filament in the gas-filled lamp operates closer to its melting temperature than the filament in a vacuum lamp.

There has been a considerable increase in the size of the average street series lamp used during the past sixteen years. Within a short time, about two years after the tungsten filament series lamp appeared in 1907, the carbon and Gem series lamps previously used were withdrawn from the market. In 1907 the average candle-power was 32, which, converted to the present lumen rating, becomes practically 320 lumens. This gradually increased to 600 lumens in 1913 when the gas-filled tungsten filament series lamps appeared. This made it possible to make such an efficient high candle-power incandescent street lighting lamp that they soon replaced the carbon arc lamps previously used. This demand greatly increased the average size of the lamps sold, the average lumens rising to over 1600 in 1917. In

1922 it was over 1700, the changes being illustrated in Fig. 3.

The smallest street series lamp regularly listed is 600 lumens, the lamps being made in eight sizes up to and including 25,000 lumens. There still is a demand, aggregating about $12\frac{1}{2}$ per cent of the series group, for lamps of less than 600 lumens. The lamp report again refers to the undesirability of using such small sizes, as lamps producing less than 600 lumens are inadequate and uneconomical under ordinary street lighting conditions, urging the substitution of larger sizes in place of the great number of small sizes now in use.

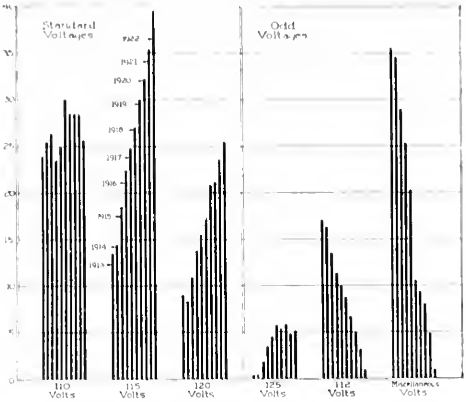

Fig. 2. Standard Voltages, 1913-1922

Demand of Lamps by Types and Sizes

While a little over 20 per cent of the total number of lamps sold in 1922 were of the gas-filled type, their aggregate wattage was over 44 per cent and aggregate candle-power over 52 per cent of the total. This is on account of their general average wattage being higher and efficiency greater than that of the vacuum type of lamps. This means that nearly half the current sold for lighting purposes and over half the light used is by means of the gas-filled lamp whose demand is one-fifth of the total number purchased.

The most popular of the gas-filled lamps are the 75- and 100-watt sizes, the demand for each of which is about $6\frac{1}{2}$ per cent of the grand total of all lamps. The most popular of the vacuum lamps is the 40-watt, whose demand is 19.3 per cent; next comes the 25-watt, having a demand of 18.6 per cent; then the 50-watt, constituting 15.5 per cent of the total demand for all lamps. The 50-watt lamp has been increasing in popularity each year since it was put on the market.

There are now six sizes of vacuum lamps regularly made for standard lighting service, 10, 15, 25, 40, 50 and 60 watts. In addition there is another 10-watt lamp supplied in a small bulb generally used for sign lighting. It seems unnecessary to have so many different sizes for standard lighting purposes, so it is hoped that the recommendation suggested awhile ago, that the demand be concentrated on but three sizes, 15, 25 and 50 watts, can be accomplished in the near future. If a 10-watt lamp is desired, this lamp in the small bulb can be used. The demand for larger sizes is now well cared for by the 75-, 100-, 150-, 200-, 300-, 500-, 750- and 1000-watt gas-filled lamps.

The above mentioned lamps cover a great majority of the total demand, but when it is remembered that they are regularly supplied in three voltages, some of them all frosted or colored, usually the smaller sizes for decorative purposes and some bowl enameled, usually the larger sizes for industrial lighting, the total number of individually different lamps becomes very great, amounting to about a hundred items. In addition, there are various sizes of lamps for sign lighting, country home, projection, floodlighting, mine lighting, street railway, train lighting, street series and 230-volt services so that the number of individually different lamps regularly listed in lamp manufacturers' catalogues aggregate over five hundred items. Furthermore there are a lot of special lamps, regularly used by individual purchasers for some device or special service of theirs, that increases the number of items to more than one thousand.

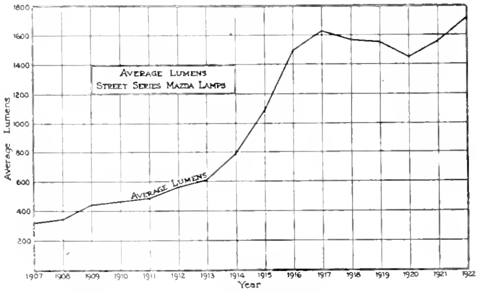

Fig. 3. Average Lumens of Street Series Lamps, 1907-1922

Lamp Developments

"Sprayed" colors have been developed which are very satisfactory. The coloring material is sprayed on clear lamps, is weatherproof and does not fade. These lamps are much less expensive than those with natural colored glass bulbs, which usually have to be made to order, and more prompt delivery can be made as the sprayed color can be quickly applied to the clear lamps in stock. There are four colors supplied which are a standard shade of red, blue, green and yellow.

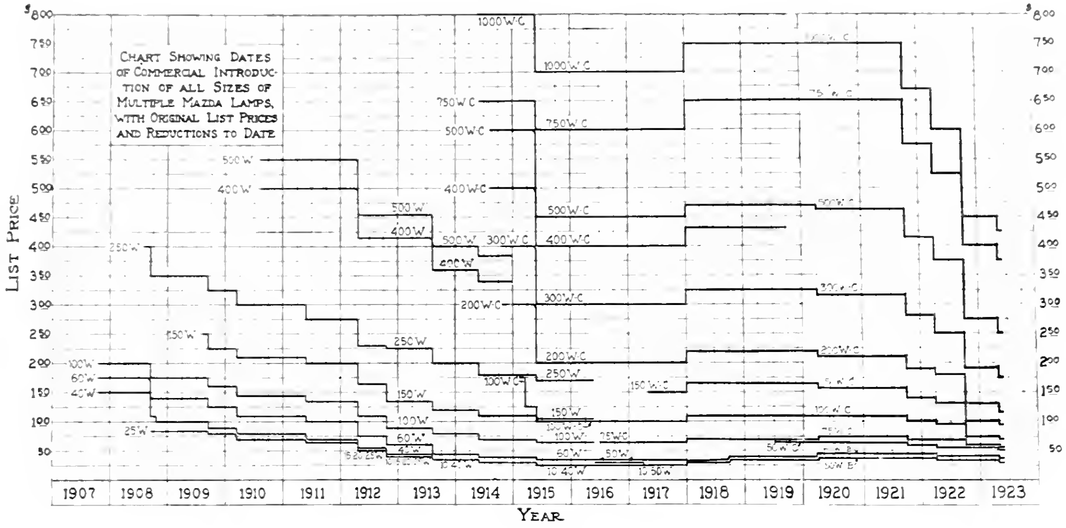

Fig. 4. Price Chart of Mazda Lamps

"All frosted" lamps are now being supplied where frosted lamps are ordered. A few years ago "bowl frosted" lamps were also quite commonly used, but in the desire to standardize on but one finish the use of bowl frosting is now discouraged. The bowl frosted lamp has been used in the past because of the belief that a considerable amount of light would be lost by the use of an all frosted lamp. As a matter of fact, with typical reflectors this is not the case, and an all frosted lamp gives much better and more desirable results in all cases.

Price Changes

On April 1, 1922, a readjustment of prices was made on Mazda lamps. Mazda B lamps were reduced about 12½ per cent and Mazda C lamps about 5 per cent. On October 1, 1922, Mazda C lamps were further reduced about 20 per cent and on May 1, 1923, both Mazda B and C lamps were again reduced, averaging about 10 per cent. The prices of Mazda B lamps are now below the pre-war level of 1914 and the prices of Mazda C lamps are the lowest in the history of the industry.

Fig. 4 shows the dates of introduction of the more important sizes of Mazda lamps in the 115-volt group, their original list prices and changes to date.

Glass and Electricity

By F. A. Connor

General Electric Company, Pittsburgh, Pa.

There is a great field for electricity in the glass industry. From the very early days the glass industry has been conservative and even at present, in most glass factories, manual operation predominates. The author describes the different processes in making plate glass and the application of electric motors to these processes.—Editor.

The art of making glass is one of the oldest in the world. Men have slaved in developing the industry for six thousand years in order that you might see the world through your plate glass window or find yourself reflected flawlessly in your mirror. Someone has said that the invention of glass was an accident into which a group of Phoenician merchants stumbled while cooking on the sand in the dim days of antiquity. According to history the Phoenicians beached their galleys on the coast of Palestine. When they had built their camp fires and tried to set up their cooking pots to prepare a meal they failed to find any stone in that desert country, so the pots were set up on cubes of soda from their cargo. The heat of the fires melted the soda and fluxed it with the sand and to their amazement they beheld a clear fluid forming as a result of the fluxing—glass.

Now here is where science tells us something: it says that to produce a fluxing of sand and soda a heat of 2600 deg. F. would have been necessary and that cooking fires didn't get that hot even in hot Palestine. You say you found glass in the Temples of the Fourth Dynasty, 4000 years B.C., eh? Where did those Egyptians get their 2600 deg. F.? Quite unable to answer, a deep blush of humiliation mantles the brow of history.

Getting down to more modern times it is stated that the first glass factory in the United States was built in the woods near Jamestown, Va., in 1608, and that the chief product was glass beads. Afterwards in many places bead factories sprang up proving a cheap and profitable kind of mint, as great profit was made by trading with the Indians and it is stated that one was established near Hanover Square, in New Amsterdam, to give the Dutch burghers a chance to recoup their fallen fortunes after paying $24.00 for Manhattan Island.

The plate glass industry, as we know it today, has changed very little in principle since about 1690 when it was first established. Stepping into the present this article is primarily to describe the plant of the American Plate Glass Co., at James City, Pennsylvania.*

This is a very modern plate glass factory and every power requirement in this complete industry is met by electric motors ranging in size from one to 400 h.p. in approximately 135 units, 97 per cent of the 10,652 h.p. connected load is developed by G-E motors. All of the alternating-current motors are 550 volt, 3-phase, 60-cycle, except those in the pump house, some distance away, which are 2200-volt, 3-phase. The direct-current motors are 125-volt.

Plate glass is made from a mixture consisting of pure silica sand, soda ash, limestone, salt cake with small quantities of arsenic and charcoal and a proportion of cullet or scrap glass being remelted with the batch. The mixture is then placed in clay pots and melted in gas fired furnaces. Modern gas fired furnaces will usually accommodate twenty pots, and eight such furnaces are in use at this plant.

In making glass the mixture is first dumped into batch wagons which haul it to filling machines which are placed near the furnaces. The filling machine is in the form of a bin which moves along on wheels and is propelled by a small motor. In front of each furnace an operator opens a gate in the filling machine which allows some of the mixture to fall into a ladle and this, in turn, enters through the furnace door and delivers its charge to clay pots. The pots in the furnace are already heated to approximately 2000 deg. F. and after the mixture has melted down they are refilled several times in order to make up for shrinkage in the batch. The pots, with the mixture, are then subjected to a temperature of approximately 2600 deg. for from 14 to 15 hr., during which the melting and fusing process goes on. Just before the pots are ready to be taken out, the temperature is reduced to approximately 2000 deg. F. At this temperature the batch is suitable for casting. All temperatures are regulated by recording pyrometers. When ready for cast-

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* The writer wishes to acknowledge the courtesy and assistance extended him in obtaining photographs and information by the American Plate Glass Co.

ing, the pots are removed from the furnace by special tongs carried on an overhead traveling crane and are delivered to the teeming crane which grasps them in jaws; they are held tight by a hand-operated "screw-down."

Considerable care is required in making the clay pots, and as there is no machine that will mould them successfully it is necessary that this be done by hand. Clay is the only practical material as the pots must stand a temperature of approximately 2700 deg. F. Up to a few years ago the only practical way of making a smooth velvety surface free of air pockets was by tramping the clay with bare feet. In these modern times a pug-mill driven by an electric motor does this work. Twelve to sixteen weeks are required for moulding and drying the pots and after all this tedious work the pots are good for not more than 20 trips to the melting furnace. Each pot is 43 inches in diameter by 31 inches deep and holds 1800 lb. of glass. The pots are dried slowly and then preheated in a furnace kiln and pushed through this kiln by means of the motor-operated mechanism shown in Fig. 1.

Fig. 1. Motor-driven Mechanism for Slowly Pushing Glass Melting Pots Through a Preheating Kiln

The filled pot after being taken from the furnace and while still in the clutches of the teeming crane has the bottom cleaned by letting it rest slightly on revolving steel brushes which knock off all loose pieces and the sides are also thoroughly blown off in order to remove any foreign substances or matter which might fall on the casting table.

After the molten glass has been skimmed by means of copper tools, which are worked around the top in order to remove any impurities, the pot, still in the jaws of the teeming crane, is taken to the opposite side of the 13½ ft. by 22 ft. flat surface steel casting table. The top of this table has already been covered with a very thin layer of fine sand to prevent sticking and chilling, the contents being poured or "teemed" in front of a huge knurled cast iron roller. At the same time the teeming crane is given a direct forward movement and the contents poured along in front of the roller. The roller, which is 26 inches in diameter by 15 ft. long and weighs approximately 13 tons, is then started in motion, being pulled by a chain connected to a motor. Crane type direct-current motors are used on the special four-motor teeming crane.

A good view of the teeming crane, the casting table and a portion of the molten plate glass while the roller is being passed over it can be seen in Fig. 4. The roller at the end of its travel mounts on wedges placed on either side which raises it slightly above the glass and allows the plate to pass under it. After the plate glass has cooled for a few seconds it is then pushed from the table into the first annealing oven. These pushers or stowing tools operate in regular successive movements and push the plate glass, after certain intervals of time, into five separate ovens which have a graded downward temperature, the first being 1200 deg. F. From the fifth oven the glass is pushed on to conveying rods into a 300 ft. leer, and still through gradually reducing temperatures moves along the leer until it comes out at the other end, 3½ hours afterward, annealed and cooled to approximately 190 deg. F. While the glass is in the leer it is carried along on leer rods in steps of approximately 15 ft., the operation being by semi-automatic motor control. The interior of the leer is lighted by arc lamps. When the glass leaves the leer it is then trimmed and examined in order that pieces having large defects such as "stones" may not be put through the expensive process of grinding and polishing. By means of special designed cranes the glass is then taken to the rough storage racks until ready for grinding

The annealing leer and also several of the specially designed appliances for handling the glass were designed by J. W. Cruikshank, Plate Glass Engineer of Pittsburgh.

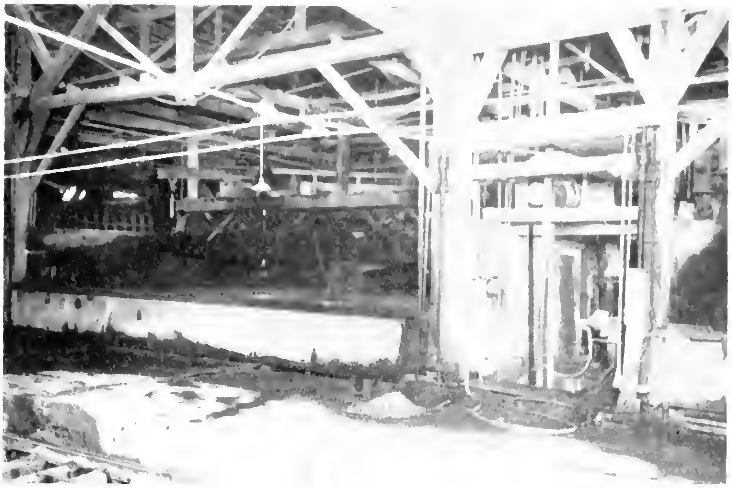


Fig. 2. Plate Glass Grinding Table, 28 Ft. 6 In. Diameter, 45 Tons Weight, Driven by a 300-h.p. Slip-ring Induction Motor. Motor at right drives a centrifugal pump for handling the grinding mixture of sand and water

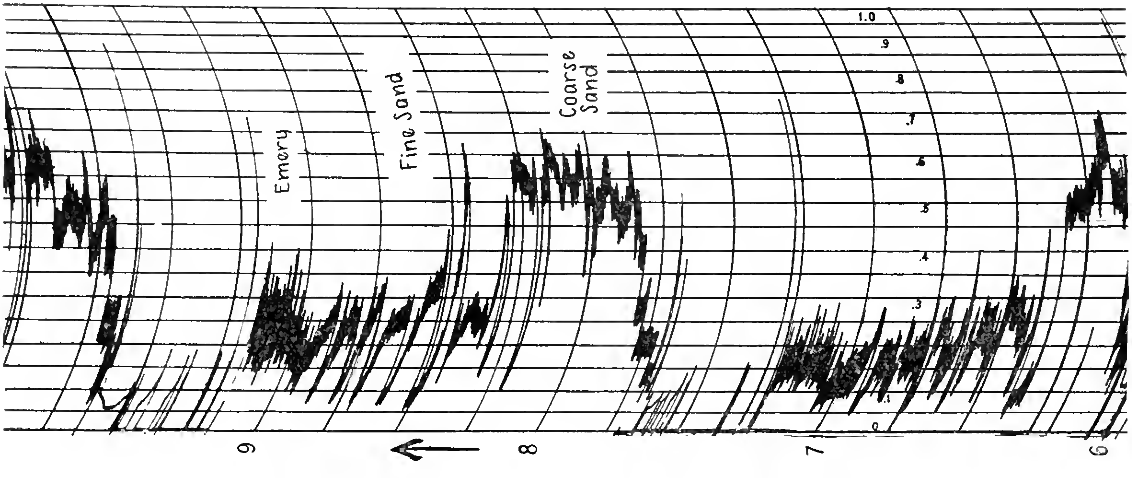


Fig. 3. Load Curve on a Motor Driving a Grinding Table Such as Shown in Fig. 2; Full Scale is 400 Kw.

The plate is laid on the grinding tables in glass stucco, a mixture of gypsum and lime, which is quick drying. This composition holds the glass on the table, but in order to further avoid accidents due to centrifugal force, wooden pegs are also placed around the outer edges of the plates to prevent slippage.

Over each circular cast steel grinding table (which is 28 ft. 6 in. in diameter and weighs approximately 45 tons) two grinding runners or discs, one of large diameter weighing 8 tons, and one of smaller diameter weighing 5 tons, are lowered on the plate glass. The under surfaces of these runners are covered with bricks like blocks of cast iron, each block weighing approximately 13 lb. when new. The two runners revolve in the same direction as the table and varying grades of sand and water are then placed upon the glass.

These runners receive their motion entirely from the friction produced between them and the plate glass and are not revolved by any external souice of power. Due to the roughness of the glass at the beginning of the grinding process the table revolves at about 15 r.p.m. and after this period (approximately five minutes), it is increased to the full speed of 26 r.p.m. Fig. 2 shows the table revolving with the two runners fairly distinguishable on top. The motor shown at the right of this photograph supplies the mixture of sand and water by means of a centrifugal pump. The grinding process is finished by use of different grades of emery being placed upon the plate glass. This emery is ground and pulverized

Fig. 4. Teeming Crane, Casting Table and Roller

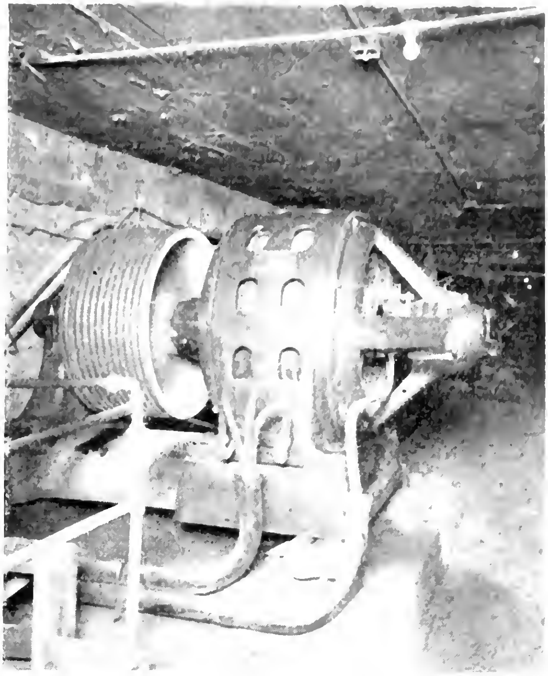


Fig. 5. Grinding Table, 300-h.p. Slip-ring Induction Motor

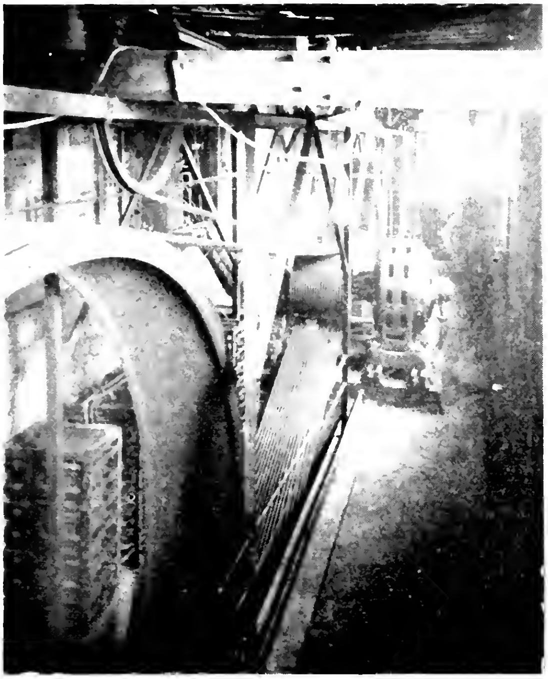


Fig. 6. Polishing Table, 400-h.p. Slip-ring Induction Motors

Fig. 7. Polishing Rouge Mixing Tanks with Motor-driven Agitators

in a ball mill which is operated by a 40-h.p. motor. The huge grinding tables are each driven by a 300-h.p. slip-ring induction motor running at 514 r.p.m. synchronous speed. A typical load curve on one of these grinder motors is shown in Fig. 3, the full scale being 400 kw. One of these motors is shown in Fig. 5.

Approximately one hour is required for grinding each side of the glass and after the plate has been ground to a perfect plane on one side and being left on the same table, it is then taken to the middle yard, where the plaster joints between the plates are raked out, any broken plates removed, unbroken plates substituted, new plaster run in between all the joints, and the plate and the table are then taken to one of the polishing machines. Each polishing machine is equipped with four runners, and attached to each runner is a number of circular blocks approximately 18 inches in diameter and to the under side of each a felt pad is attached. These felt blocks bear against the surface of the glass. Red rouge or roasted sulphate of iron held in suspension by water is then applied for polishing. The polishing tables revolve at approximately 22 r.p.m.

After an hour and twenty minutes of this and a repetition of the whole process for the opposite side of the plate all that man has been able to learn in sixty centuries to make a perfect plate glass has been done. Each polishing table is driven by a 400-h.p. slip-ring induction motor operating at 514 r.p.m. synchronous speed. Several of these motors are shown in Fig. 6.

A typical load curve on one of these polishing motors is shown in Fig. 8, the full scale being 400 kw.

The red rouge for polishing is constantly agitated and is mixed in oblong tanks which permit of a thorough mixing and three such agitators are driven by a 7½-h.p., 720-r.p.m. induction motor as shown in Fig. 7.

All of the seven grinding and eight polishing machines are rope driven as shown in the photographs, except one polishing machine which is chain driven as will be seen in Fig. 9. The American System of rope drive is used and has given very satisfactory results.

After the glass has been given a fine polish it is washed off and taken to the cutting tables, where it is handled by a special type crane as seen in Fig. 10, which was designed particularly for this class of service. The plate glass is then carefully examined, all defects noted, and cut into the proper sizes and placed in the wareroom from whence it is packed and shipped.

Each grinder and polisher motor is controlled individually from a point just in the rear of the grinder and polisher machines. After years of experience it was decided that this was the logical place as it gives each operator instant control of each machine. The control consists of a hand operated master switch and an automatic control panel

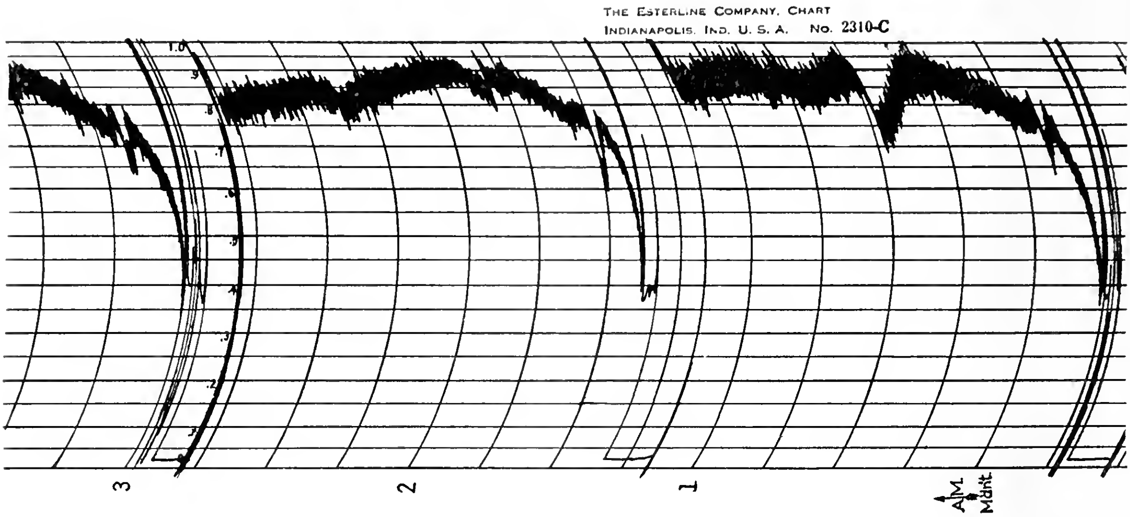


Fig. 8. Load Curve on a Motor Driving a Polishing Machine; Full Scale is 400 Kw.

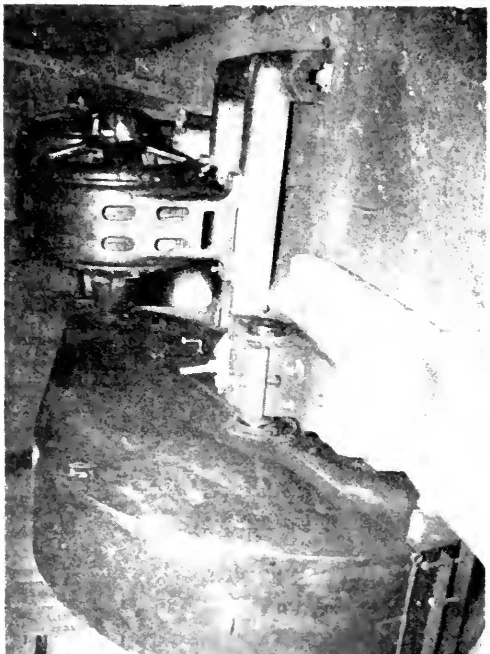


Fig. 9. Motor Chain Drive of One of the Polishing Machines

Fig. 10. Special Crane for Handling Plates of Glass

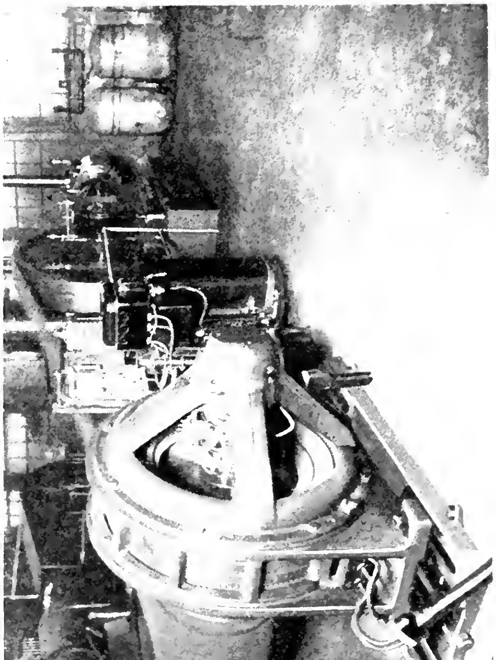


Fig. 11. A 100-h.p. Slip-ring Induction Motor, and Control Equipment, Belted to Air Compressor

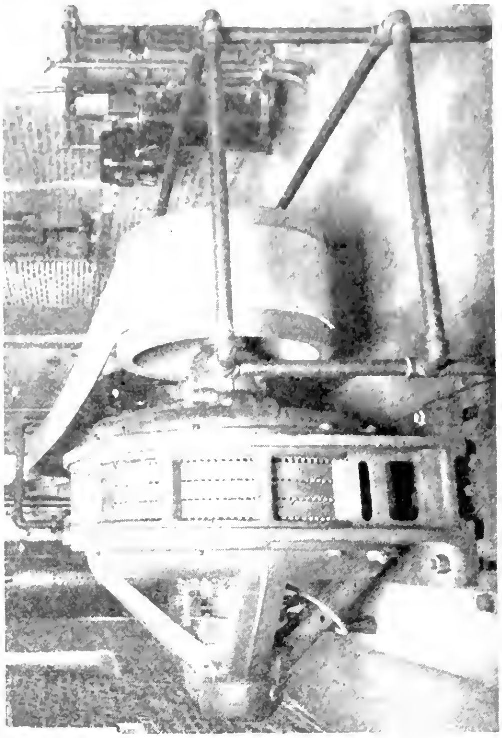


Fig. 12. Another Source of Compressed Air for Use in the Manufacturing Operations

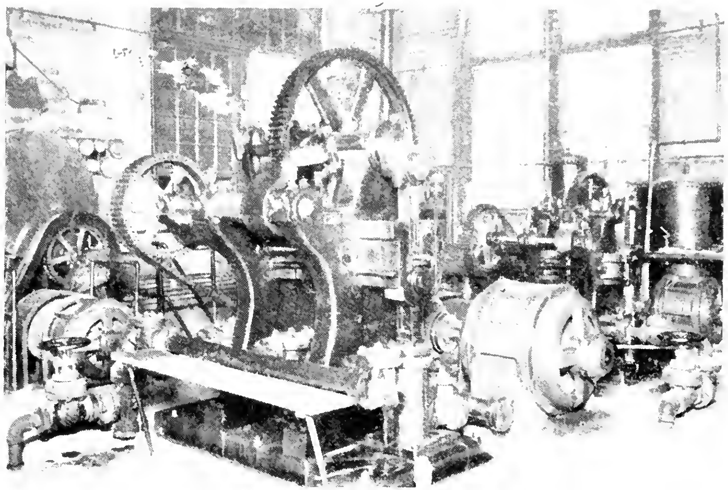


Fig. 13. Motor-driven Hydraulic Triplex Pumps for Raising and Lowering the Heavy Grinder Disks

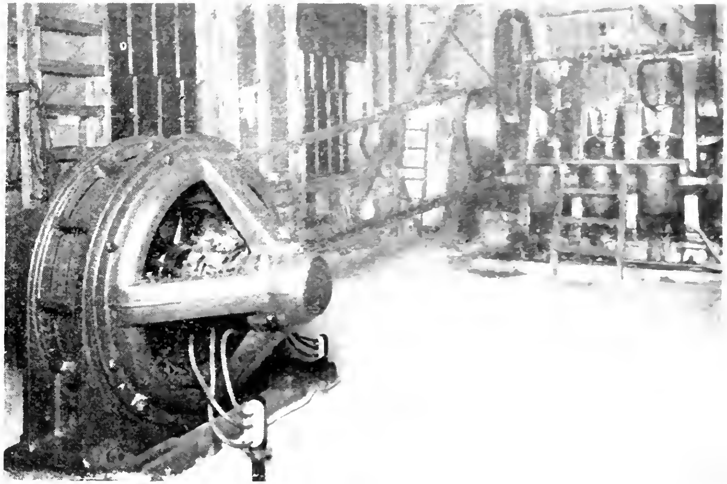


Fig. 14. Motor-driven Triplex Pump for Supplying Water for Washing Operations, etc.

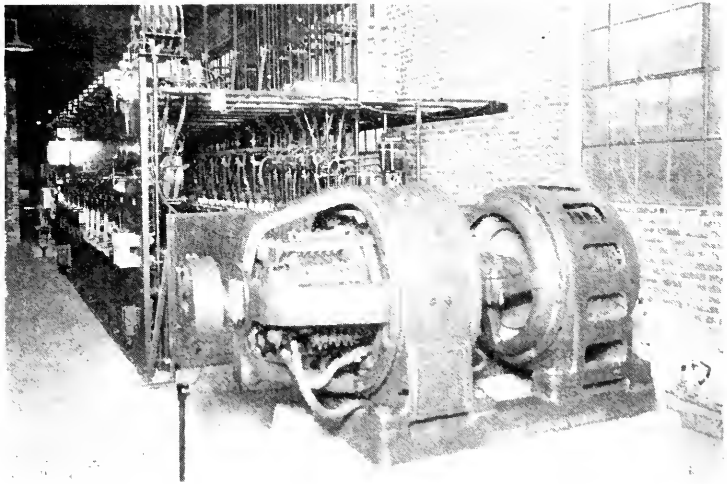


Fig. 15. Synchronous Motor-generator Set for Supplying Direct Current; Plant Switchboard in Background

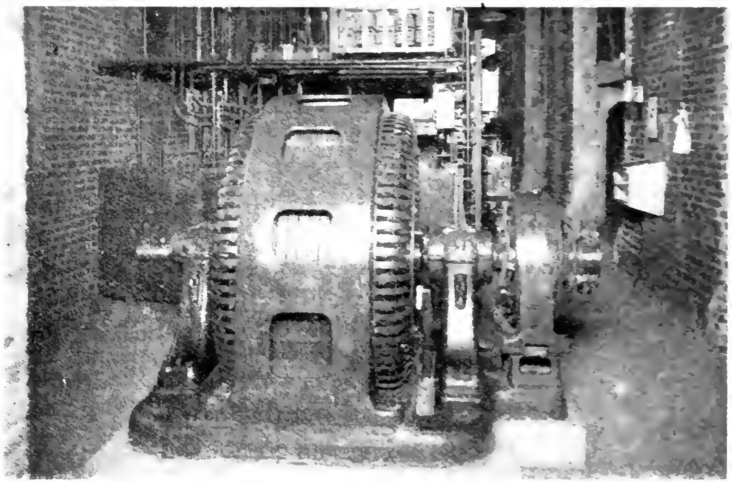


Fig. 16. 1500-kv-a. Synchronous Condenser Installed to Raise the Power-factor from 75 to Above 95 Per Cent

which provides for low speed for a few minutes at start until full speed is desired.

Quantities of air for raising sand to the grinder tables and for use in the casting hall in blowing off the casting table and opening furnace doors, etc., are supplied by motor-driven air compressors, one of which is shown in Fig. 11. A similar motor-driven air compressor for the same purpose is shown in Fig. 12.

In addition to these drives, alternating-current motors are used to operate the fire pump, plaster pumps, plaster mixers, carpenter shop, polisher agitators, centrifugal pumps for sand graders, centrifugal pump for emery graders, emery grinders, sand hoist, coal crusher, coal conveyor, casting room pumps, casting room fan, gas producers, machine shop and motor-generator sets.

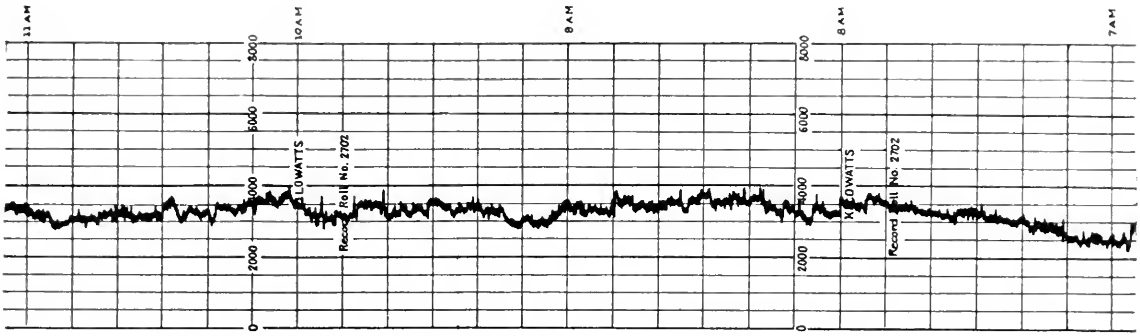


Fig. 17. Section of a Curve-drawing Kilowattmeter Chart Showing the Typical Load of the Plant

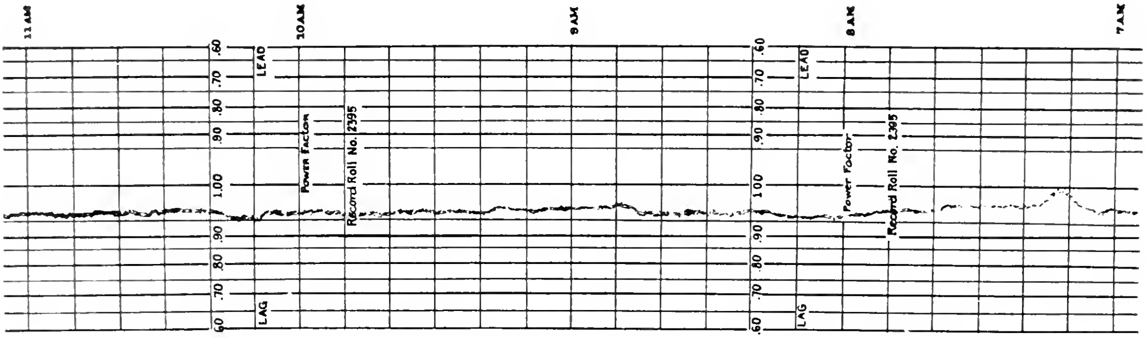


Fig. 18. Section of a Curve-drawing Power-factor Chart Showing the Power-factor of the Plant

The heavy circular iron runner discs, over each grinding machine, require approximately 600 lb. of water pressure for raising and lowering them on the glass grinding tables, and this pressure is supplied by an hydraulic accumulator which in turn is supplied with water through motor-driven triplex pumps as seen in Fig. 13. One of these pumps is driven by a 25-h.p. squirrel-cage motor, and the other by a 50-h.p. squirrel-cage motor.

Great quantities of water are required in a glass factory particularly for the grinding tables and for washing off the glass and the floors. This is supplied by three 100-h.p., 450-r.p.m. slip-ring induction motors driving triplex pumps, one of which is noted in Fig. 14.

The entire direct-current motor load of the plant is taken care of by one 125-k.w., 1200-r.p.m., 125-volt compound wound synchronous motor-generator set shown in Fig. 15, although a 125-kw. induction motor-generator set is held in reserve. Direct current is used for the motors on the two transfer cars which handle the grinding and polishing tables, the power house and casting room cranes, the teeming crane, the special wareroom cranes and the two main leer motors.

A 28-panel switchboard controls the different circuits throughout the plant. An end view of this board is seen in Fig. 15. In order to show at a glance just how the plant is operating, the incoming line panel is equipped with voltmeter, ammeter, kilowatthour meter, frequency meter, power-factor meter, curve-drawing kilowattmeter and curve-drawing power-factor meter. The company, at present, purchases its power, although in case of emergency they are prepared to start up their private generating plant and generate a large portion of their requirements. A double bus system with double-throw switches permits the operation of any motor circuit either with purchased power or from their private generating plant.

The generating plant consists of three 781-kv-a. 150-r.p.m., and three 500-kv-a., 180-r.p.m., 600-volt, 3-phase, 60-cycle General Electric gas engine driven generators. The power is purchased from the Keystone Power Corporation and is transmitted at 44,000 volts, 3-phase, through two lines from the main generating station at Ridgway. A 6000-kv-a. bank of transformers steps the voltage down to 550. The glass plant is in operation 24 hours a day, except Sundays, and the load over the entire period is well represented by the load curve taken from the curve-drawing kilowattmeter, as indicated in Fig. 17.

About two years ago the power-factor of this plant varied between 70 and 80 per cent. Since power is purchased on a basis which provides a penalty for low power-factor, it was decided to put in a 1500-kv-a., 900-r.p.m. 550-volt synchronous condenser for corrective purposes and since then the power-factor averages more than 95 per cent, as indicated by the power-factor curve in Fig. 18. The synchronous condenser with its direct connected exciter is shown in Fig. 16.

The condenser has proven to be a very profitable investment and has been paying large dividends by maintaining a high power-factor.

This plant has recently been purchased by the Durant interests, it being the first independent plate glass factory to change hands in several years, and we believe that their decision to take over this plant rather than any other of the independent glass factories, was due largely to the completeness with which it was electrified. The present 60-cycle equipment has been in operation for about three years, although they had operated their plant for approximately ten years previously by 25-cycle motors of various makes.

This plant has probably the most complete modern equipment of any of the plate glass manufacturing concerns to-day and the quality of the glass produced is unexcelled.

* * *

The Origin of Ions in the Unsustained Glow Discharge

By Prof. K. T. Compton
Palmer Physical Lab., Princeton University

and

T. E. Foulke
Research Division, Edison Lamp Works

This is our first contribution from the new Research Division which was established at Harrison a few months ago. The article shows that there are sufficient residual ions present in any gas to start a discharge when a sufficiently high voltage is applied. Attention is drawn to the application of the Einthoven galvanometer for registering minute currents for very short intervals of time.—Editor.

Introduction

In the unsustained discharge using a cold cathode it is of interest and importance to know the origin of the initial ions. It is known that electric fields which are strong enough to produce a spark or glow discharge in a gas are quite incapable of extracting ions from the metal electrodes or of causing the formation of ions from molecules.

To account for sparking in a gas Townsend developed a theory in which any free electrons present in the gas may be multiplied by collisions with gas molecules. The theory postulates that the energy at impact, due to velocity gained in the applied field, must be great enough to cause ionization of the molecules. With sufficient voltage between the electrodes, both electrons and positive ions may ionize at collisions until the current density becomes great enough for the discharge to occur.

The general belief is held that a few ions are continually being formed everywhere in the earth's atmosphere, and that the number of ions formed will equal the number lost by recombination over a sufficiently long interval of time. If the original ions are produced in the gas in a haphazard fashion, as would be expected if due to penetrating radiation arising from the minute traces of radioactive material found everywhere in the earth, the discharge might not occur immediately after the application of the voltage, but would occur whenever ions happened to be formed in a location favorable for building up the discharge current. The ions if generated too close to the anode would not ionize sufficiently to reach sparking density. The spark or discharge would occur, however, as soon as a pair of ions are formed far enough away from the anode to multiply to the critical value.

The less favorable the location of the original ions, the greater would be the voltage necessary to start the discharge. Thus we should expect that the average interval of time between application of the voltage and setting in of the discharge would be increased by reducing the frequency with which the original ions are produced and also by reducing the voltage toward the minimum value capable of producing the discharge.

The number of pairs of ions formed per cubic centimeter in air at normal pressure is only *five or six* per second. Thus it seems possible to measure the variable time-lag between the application of voltage and starting in of current that reaches the discharge value. Furthermore, if the original ions are produced from radiation originating in the earth, it should be possible to cut the time-lag by placing radium near the discharge tube or to increase the time-lag by shielding the tube from the earth's radiation.

Experiments

The discharge tube consisted of concentric cylinders of nickel in mercury vapor, the vapor pressure of which was controlled by placing the tube in an oven. The working temperature of the vapor was determined by adjustment so as to give the minimum spark potential with the smaller cylinder as anode. The temperature used was 190 deg. C., corresponding to 19 mm. pressure. The voltage required to start the discharge was 264 at the above pressure. However, 300 volts was used in the experiments to insure occurrence of the discharge within a few seconds after the application of voltage.

The time-lag between the application of voltage and the starting of the discharge was measured by means of a string oscillograph designed by Prof. Trowbridge of Princeton University and made available for this work. It consisted of two separate elements recording simultaneously on a continuous photographic film, which was delivered from the camera, automatically developed, and fixed. Time coordinates are lined across this film at 0.01-second intervals by the shadows cast by spokes of a rotating wheel, driven and controlled by a standard tuning fork. One string was connected with suitable resistances to serve as a voltmeter and the other with a shunt to serve as an ammeter, so that they registered on the film the instant of application of the voltage and the instant of setting in of the discharge.

This oscillograph made it not only possible to record the time-lag but due to ease and speed of operation allowed a large number of oscillograms to be taken, which is necessary to obtain even fair averages.

Results

Preliminary results showed a wide variation in the time-lag, thus confirming earlier views on the formation of ions. To show the approach to this state of haphazard formation of ions the following procedure was followed: The gas was put into an ionized condition by running the discharge for a definite time of 15 seconds; the voltage was then cut off for a definite time interval and applied again. The time-lag between the application of the voltage and the starting of the current was measured after various intervals of time between the cutting off and application of the voltage. If this time interval is short, say 0.2 second, the time-lag is never over 0.001 second (which was the limit of detectability). This time-lag increases with the time interval, rapidly at first and finally becomes quite erratic but with a constant average value near 0.7 second under the experimental conditions used.

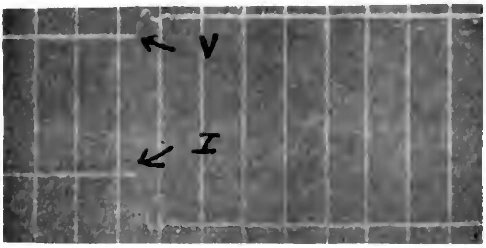
For the shorter intervals of time, residual ions from the preceding discharge evidently accounted for the quick starting of the discharge when the voltage was reapplied, but with the longer intervals of time the ions present are evidently not residual ions but are being produced at a constant rate by some external source.

A few of the oscillograms are given in Fig. 1 and the results are plotted in Fig. 2. The average values are plotted in curve A and the limits of observation are given in A' and A'', for the time-lag against the interval of time between cut off of voltage and reapplication.

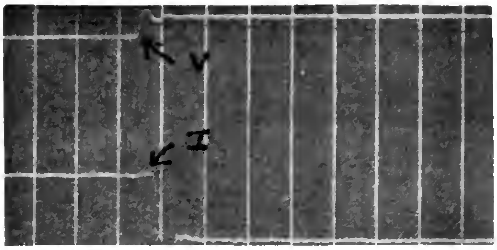
Effect of Radium

The next set of observations was made with radium near the tube. The time-lag never exceeded about 0.01 second and was usually only 0.003 second for the longest time interval.

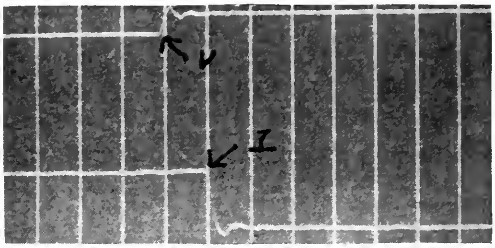
While it is evident that the presence of the radium decreased the time-lag, by increasing the number and frequency of formation of initial ions, this by no means points to the nature of the source of the original ions. However, it appeared to be a simple matter to determine if they are of radioactive origin,



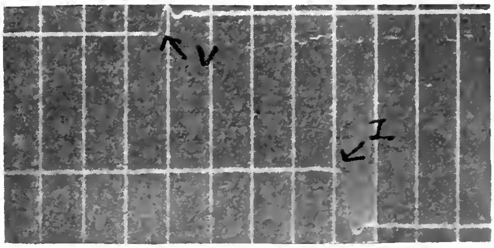
Time Interval 0.19 Sec.



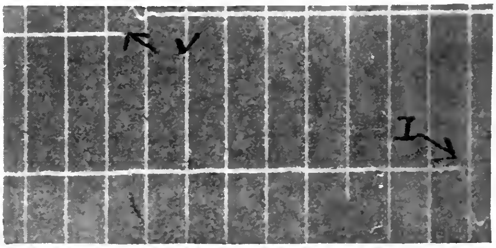
Time Interval 5.0 Sec.



Time Interval 10.0 Sec.



Time Interval 20.0 Sec.



Time Interval 40.0 Sec.

Fig. 1. Oscillograms showing Time-lag Between Voltage and Current in Discharge. The vertical lines are located at 0.01-sec. intervals

by shielding the discharge tube with lead, which was expected to cause the time-lag to increase.

Effect of Shielding

The tube was placed in a jacket of lead 0.63 cm. thick. The temperature of the furnace was varied to get the same pressure conditions for minimum discharge voltage. Under these conditions it was found the minimum discharge voltage was 120 volts higher than the previous test voltage; or, in other words, the minimum voltage had increased from 264 to 420 volts. The temperature (and corresponding pressure) was varied above and below the minimum point as it was thought that the tube might have developed a leak, but it was soon found that the low discharge voltage could only be obtained immediately after the higher voltage was applied. On waiting one or two minutes after the voltage was cut off, only the high voltage would start the discharge. Time-lag measurements were not made because they are not comparable with data given previously. The shield was then removed and the discharge was found to occur at 264 volts as in the experiments mentioned already. The results justified the belief that the time-lag was increased by the shielding lead to longer than one-half hour.

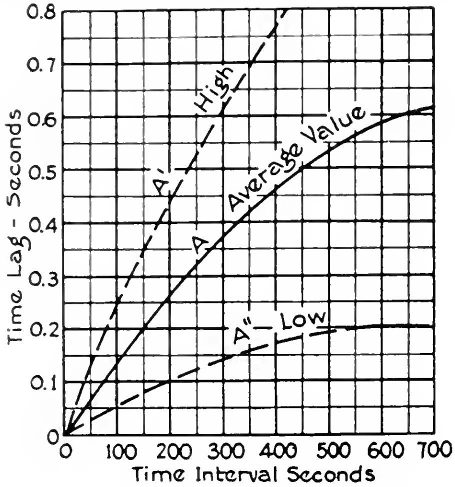


Fig. 2. Relation Between Interval During which Discharge was Discontinued and Resulting Time-lag Between Applied Voltage and Current

This last experiment, in which the starting voltage was increased by shielding, suggested that the starting voltage might be lowered by the presence of the radium. This experiment showed, however, that the lowering was less than two volts.

Conclusions

These experiments lead to the following conclusions:

(1) The essential number of original ions in a discharge tube of the type studied are due to the radiation from the radioactive elements in the earth. The reasons for believing this are these: (a) By shielding the tube with lead the number of ions generated can be reduced to a value insufficient to start the discharge. (b) The discharge can be aided by exposing the tube to a source of radioactive emanations.

(2) The results obtained on the time-lag are in agreement with the view that the ions are formed due to the earth's radiation and that the multiplication to discharge value can readily be explained by means of Townsend's theory.

In conclusion, the writers wish to thank Prof. Trowbridge for his ready co-operation and to Mr. C. C. Van Voorhis for his assistance in making the observations.

Electric Drive in the Printing of Newspapers

By Carl F. Scott

Bloomfield Works, General Electric Company

A description of the complete process of newsprint paper manufacture on an enormous scale by a 100 per cent electrified plant appeared in our last May issue. The following article outlines the application of electricity to the next phase in the production of the finished newspaper, that is, the actual printing. The early part of the article is devoted to a detailed but brief historical review of the development of the modern types of newspaper printing presses. The remainder describes the load characteristics of a press, the manner in which the electric drive is arranged to fulfill the requirements completely, and the control equipment employed.—Editor.

Historical Development of the Newspaper Printing Press

Pause for a moment and picture a modern metropolis without newspapers. Then if you feel as most people do, that you can't do without them, consider briefly the wonderful organization and equipment that has made possible the gathering and dissemination of news.

We will in this article outline some essential features of the mechanical and electrical equipment of the publishing office, whose life blood is the incoming news flashes and advertising contracts, and whose nerves of motion are the electric control. Between 200,000 and 300,000 h.p. produce through the newspaper press 31,000,000 daily papers in the United States from 2350 establishments. A quarter of a million people and half a billion of capital are employed in the publishing trades.

Besides daily papers, 17,000 different periodicals find readers in this country. It is with the daily newspapers, however, that we have to deal here.

Printing from blocks was known in China in the early part of the Christian era. Paper was made there, from the inner bark of the mulberry tree.

The Arabians learned the art of making paper from the Chinese. They were known to have made paper from cotton about the year 1000.

Printing from blocks for ornamentation of fabrics came into England in the 12th century.

The making of paper from rags was also introduced in England in the 12th century.

Playing cards were printed in the 14th century.

Paper made from rags replaced vellum or sheepskin in the 15th century about the time that movable types were invented by Coster of Haarlem, Holland; and put into practical use by Gutenberg, a German who is regarded as the father of printing. Gutenberg built presses in 1455.

In 1475, William Caxton, the first printer in England, translated and printed in English a book which had been printed in Bruges or Cologne somewhere between 1471 and 1474.

Books printed before the year 1500 are known to collectors as "Incunabula" and are very valuable.

One of the first newspapers was the *Notizer-Scritte*, issued by the Venetian Government in 1566. It could be read upon payment of a gazetta, a small coin. From this comes our word "gazette."

The first English newspaper was the *London Weekly News*, issued in 1622. The first French paper was the *Gazette de France*, and started in 1631.

The first newspaper printed in America was *Public Occasions*, issued in Boston in 1690. The Colonial Government suppressed it after the first issue. Printing had been suppressed in New York two years before by royal authority.

The first English daily was the *London Daily Courrant*, started in 1702. In 1703, came the first penny paper, the *Orange Postman*.

The first American daily was the *Pennsylvania Packet*, later known as the *General Advertiser*, which was started in 1784.

The next year saw the inception of the *London Times*, by John Walter, father of an illustrious line of publishers.

In 1797, there was started the *Commercial Advertizer*, now the *New York Globe*, the oldest paper in America that still runs.

The *New York Evening Post* was next and started in 1801.

It was the growing industrial and commercial life of the 19th century which expanded journalism beyond the purely literary and political character it maintained in the early two-page and four-page sheets. These changes, especially in America, were hastened by the development of four factors: cheap paper, improved printing machinery, machine composition, and stereotyping.

All these early newspapers were single sheets or given one fold, making four pages. They were of course all printed on hand

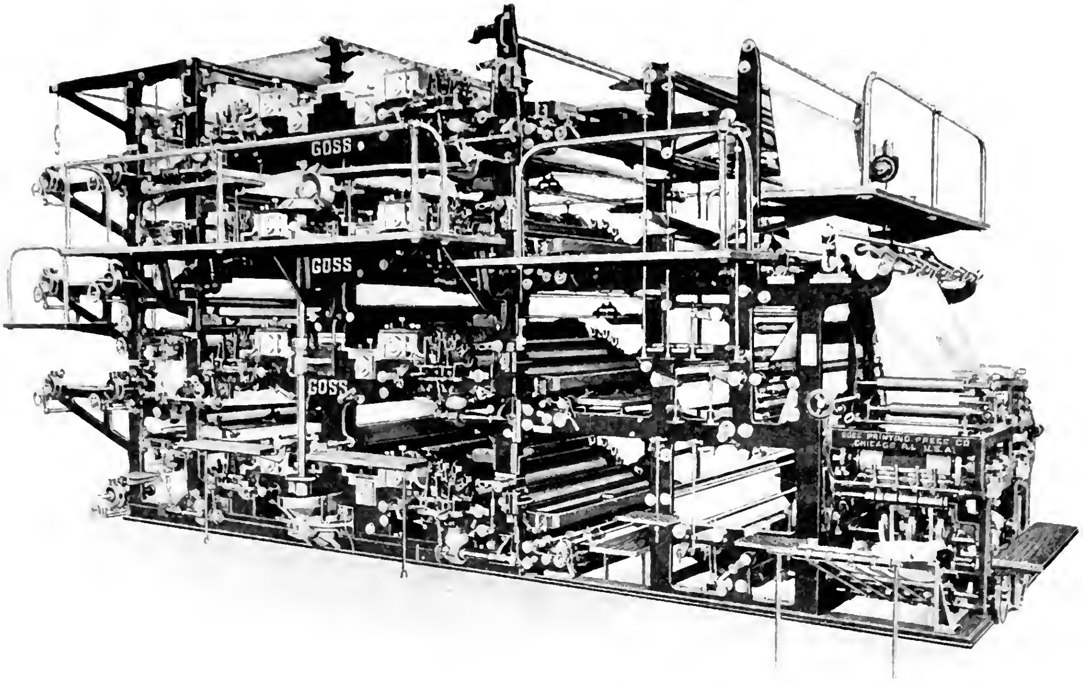


Fig. 1. Straight-line Octuple Press. Capacity 36,000, 32-page papers per hour. The press has 4 decks, 4 pages wide, 64 plates. This machine is typical of large decked type presses in common use in metropolitan offices from about 1900 to 1915

presses, like those made familiar to all readers of "Franklin's Autobiography." There had been considerable mechanical ingenuity displayed in these hand presses which were first crude affairs of wood, but by the end of the 18th century were of iron and even adapted to be run by horse power. No press took over a fraction of a horse power in those days and this was two-armed or four-legged power.

Printing presses were not run by steam power till 1814, and not by electric power till the latter 80's.

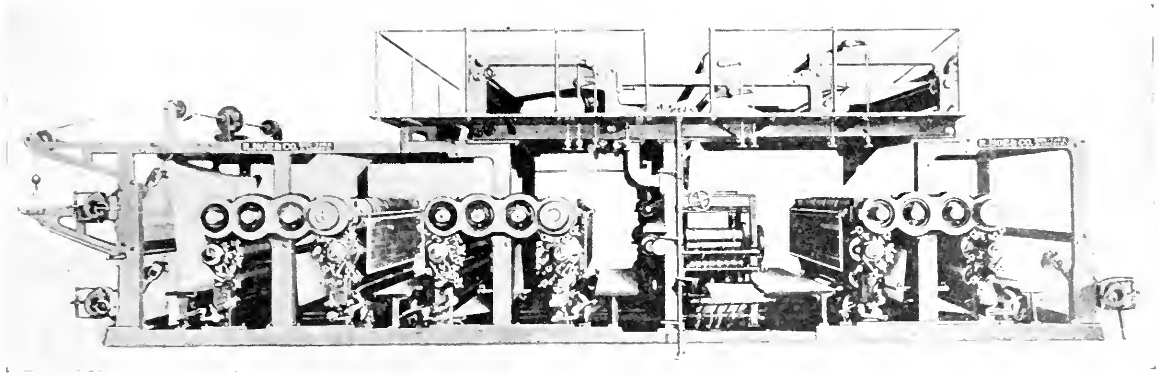


Fig. 2. Unit-type Low-pattern Sextuple Press. Capacity 36,000, 24-page papers per hour. Typical of present day construction. Presses are built in this form with many units in a straight row, and arranged for several combinations of units. One large press room has 25 units in a single row. The controller shown in Fig. 9 operates twelve units, equivalent to four presses like that shown above, and arranged to run as five sextuples, or as three octuples, or as two decuples and one quad

A great impetus was given to printing by the development of the paper-making machine by Fourdrinier in 1806, which made cheap paper possible. It is a remarkable tribute to this genius that the Fourdrinier machine, though greatly improved over the original, is still the standard of modern paper making and still carries the inventor's name. This can be said of few other machines of so early an origin.

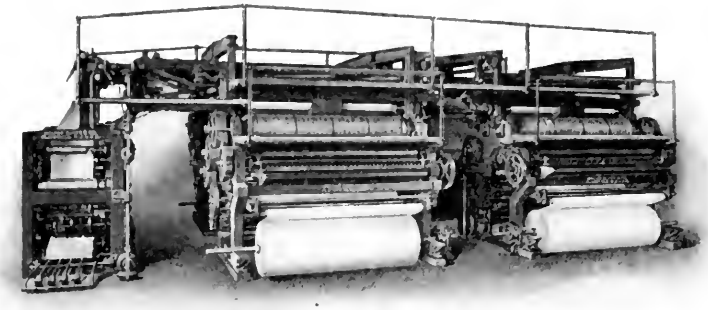


Fig. 3. **Multi-unit Double Quadruple Combination Octuple Press. First built in 1910. This press has two drives which operate independently or in parallel**

The hand press could turn out 200 copies an hour.

Something approaching speed came with the invention and development of the flat-bed cylinder press. The invention of this machine is attributed to F. Koenig, a German, in 1812 and 1813. He built a continuously revolving cylinder press for the *London Times* in 1814. This press was started Nov. 29, 1814, the first press to be run by steam power. The speed is variously given at 800 to 1100 impressions per hour.

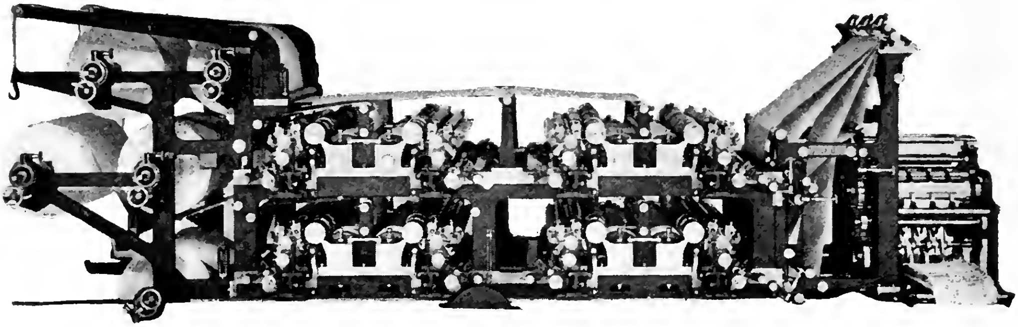


Fig. 4. **Sixteen-page Tubular Plate Press. The plate cylinders are 7½ inches in diameter, and the plate surrounds the cylinder. Capacity 25,000 to 30,000, 16-page papers per hour**

The first flat-bed cylinder press used in America was one built by the Frenchman Napier, the inventor of grippers for carrying the sheets around the cylinder. It was imported in 1825, for the *National Intelligencer* of Washington, and was often called the Napier Gripper.

Robert Hoe, a Scotchman, born in 1784, came to America in 1803, and by 1825 had become a manufacturer of printing presses. He bought the rights to the "Washington" hand press from Rust and Turney, and his firm turned out in all over 6000 of them.

In 1827 and 1828, Hoe copied and improved on the Napier press, and began the production of a long series of flat-bed cylinder presses: the single large cylinder, the single small cylinder, the double cylinder, and others. Hoe died in 1832 but his son continued his work.

These early flat-bed cylinder presses reached a speed of 2000 per hour, limited by the speed with which the sheets could be fed by a boy. They were printed on one side, and a second run was required for printing on the other side.

We read in the history of the *New York Sun*, which was started by Benjamin H. Day on Sept. 3, 1833, that he had to begin the venture with a hand press at 200 sheets an hour. Cylinder presses were too few and too costly.

In those days, it took eight hours to run off an edition, and at that there were only four pages to the sheet. To increase the output, the double-cylinder machine with two feeders was developed. By 1843, the circulation of the *New York Sun* was 38,000 and we read that it employed two Hoe-Napier double-cylinder machines, with a combined capacity of 4000 copies per hour, printed on both sides.

The necessity for still greater production resulted in the development by Hoe of the type-revolving press in 1846, which largely supplanted other forms up to the introduction of the rotary web press in the early 70's.

In 1871, Hoe brought out the first rotary web machine of that manufacture. The date of 1873 or 1874, however, is given to "Web No. 1" which is said to be still in use though somewhat modified. This Hoe press was described as "very compact." It was 20 ft. long, 6 ft. wide and 7 ft. high. The speed was 12,000 per hour.

The first Hoe web press, like all the early rotaries was a 2-page wide, single-roll machine, turning out two 4-page papers per revolution, or one 8-page. The first Hoe had a "gathering and delivering cylinder," the forerunner of the modern folder.

In 1872, Walter Scott, a Scotch pressman who came to America in 1869 and was employed by the *Chicago Inter-Ocean*, invented a press which was adopted by his employers. Scott's first presses were built in Chicago by H. Hart and later by C. Potter, Jr. The manufacture was then moved to Plainfield, N.J., where the present factory was built in 1884.

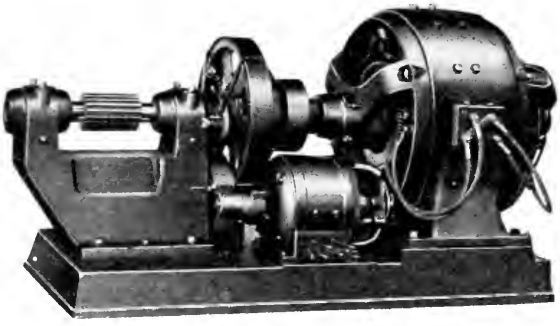


Fig. 5. Direct-current Double Motor Drive, 100 h.p.

Scott, who was a prolific inventor, put the first folder on a Bullock Rotary, perhaps the first successful rotary web press, built first in 1865. He invented the angle-bar first used for bringing the webs up to the folder, before the days of the triangular former. The angle-bar also made the 4-page wide press possible.

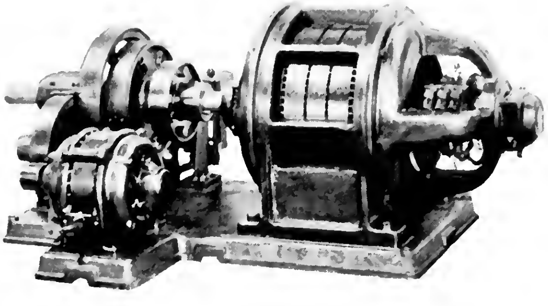


Fig. 6. Alternating-current Double Motor Drive, 40 h.p.

Hoe's first 4-page wide or "double" press came out in 1874.

The triangular former, which was one of the important elements that made the modern high-speed newspaper press possible, was introduced in 1881.

In 1885, the Goss Printing Press Co. was founded in Chicago and its first presses were 2-page wide, 4- and 8-page machines.

In 1887, Hoe built for the *New York Herald* the first quadruple press, or 2-unit, 4-page wide machine, called a quad because it had four times the capacity of the early single press, or twice that of the double press. Its capacity was 24,000 16-page papers per hour, using 32-plates. Like the double supplement, the rolls were at floor level and at right angles.

A book printed in England in 1888, "Modern Printing Machinery," describes no newspaper presses of more than one roll. The Hoe press described is the 1875 model.

In 1888 electric light had come in. It reduced the temperature of press rooms considerably as well as giving better light. In 1887 electric motors were first being used on newspaper presses. In 1922, a Sprague motor was running a press at the *Boston Globe* which it ran first in 1887.

The first sextuple, or 3-roll, 4-page wide, 48-page press was built in 1889-1890. It had a capacity of 24,000 24-page papers per hour.

Scott's first color press came out in 1892 and Hoe's in 1893.

The first octuple, or 4-roll, 4-page wide, 64-page press was made in 1895.

1907-1908 saw the high-speed rotary camless folder and the first high-speed presses, 300 r.p.m. of the cylinders, 36,000 papers per hour. By 1910, presses of this speed began to be generally installed.

In 1909, the Duplex Printing Press Co. brought out its tubular plate press. The essential difference between this press and the semi-cylindrical plate press heretofore built was in the plate cylinders. The plates surround the cylinder, one plate around instead of two around. The cylinder is 7¼ in. in diameter outside, instead of 14½ in., so the same size newspaper may be printed one newspaper per revolution instead of two. Thus for the same surface speed of the web the revolutions of the tubular plate cylinders will be twice that of the semi-cylindrical plate press.

Fig. 7. D-c. Controller for Drive Shown in Fig. 5

About 1915, H. A. Wise Wood, inventor of the Autoplate, built a press to run at 72,000 per hour, 1200 cylinder revolutions per minute.

The early presses, taking more than one roll, were usually of the decked type. Modern presses are almost all of the low pattern type, taking more floor space, but making all parts accessible from the floor. This results in reduced labor in plating and dressing the press, shortens the time of make ready, and makes shorter and easier the job of clearing a press after a web break.

The Power Requirements of a Newspaper Press

The power applied by the motor is used to:

(1) Overcome gear and bearing friction.

(2) Rotate the plate cylinders, impression cylinders, and inking cylinders, the two former being pressed together under the impression.

(3) Keep the web in motion under the tension supplied by the brakes on the roll spindles and by the rollers over which it passes.

(4) Rotate the folding mechanism, drive the cutting knives and folding blades, and overcome gear, bearing and cam friction in the folder.

(5) Overcome the friction of the web on the rollers.

(6) Overcome the friction of the ink distributing rollers and the drag of the ink.

(7) Accelerate the rotating masses.

The combined resistance of these several elements, excluding acceleration, produces a characteristic curve in which the torque increases slightly with the speed. The horse power therefore increases somewhat faster than in direct ratio to the speed increase, but slower than in the ratio of the square of the speed.

Most large presses are arranged so that their separate units can be disconnected. For example, a 5-unit, 40-page press may at times be operated as a 3-unit, 24-page machine, and again as a 4-unit, 32-page machine. With one or two entire units disconnected, the load on the motor is greatly reduced. Provision for such operation must be made in the control system to secure smooth acceleration and proper speed control under all conditions.

One of the most important elements in press control is uniform acceleration and deceleration. Any jerks or sudden changes in speed will break the web. A broken web is always a source of delay, and time is the essential element in newspaper production. Also it may damage the rollers and blankets and perhaps spring the spindles if the paper clogs up.

The gear, bearing, and roller friction are a very large part of the total resistance. While running, these are greatly reduced by the oil films which form between the gear teeth and between journals and bearings. At standstill, the film usually does not exist. To put it another way, static friction is much higher than running friction. This applies to rollers, inking devices, and folders, as well as to gears and bearings. Cold oil and cold ink add to the static friction.

Consequently, it takes much more torque to start the press than to run it; from 150 to 300 per cent of the running torque. If this torque were applied without some way of restraining it as soon as the static friction were overcome, it would be available for acceleration to an extent that would jerk the whole machine, break the web, and perhaps strip the gears.

Furthermore, it is necessary to give the press a low, steady speed of the web (about 40 ft. per min.) for threading it in. It is also necessary to turn the cylinders over very slowly for putting on plates. In the early presses, from 1873 to about 1885, threading-in was accomplished by "barring-over" the press by hand, with the power off.

Later various forms of mechanical slow motion came to be employed. Presses were driven by belt, usually at one printing speed. The most usual form of mechanical slow motion consisted of a set of back-gears, with a ratio of 20:1, or more, associated with the loose pulley of a pair of tight and loose pulleys. The belt ran continuously on the loose pulley, and power was applied for starting the press on slow motion by means of a clutch which brought the back-gears into engagement. The press was brought up to printing speed by shifting the belt to the tight pulley. A man was usually stationed at the belt shifter, for in case of emergency the only way to stop was to signal to the man, who would throw off the belt and apply a hand brake interlocked with the belt shifter.

The modern slow motion most commonly used consists of a separate motor called the starting motor, mounted on the same base with the main motor and connected to the shaft of the main motor through double-reduction spur gearing and overrunning clutch. The gearing has a total ratio of about 30:1. On starting the press, the starting motor only is connected to the circuit, turning the press at a speed of about 10 cylinder revolutions per minute. When ready to go on speed, the main motor is connected to the circuit through the control, and its shaft runs faster than it had been driven by the starting motor. This causes the clutch to overrun, the clutch pawls disengaging from the ratchet teeth by centrifugal force and severing all mechanical connection between the main and the starting motors. Shortly thereafter the starting motor is electrically disconnected at the control. The starting motor is usually about one tenth the horse power of the main motor.

A conspicuous advantage of the two-motor drive is that the threading speed is substantially constant regardless of the load; whereas with a single-speed motor drive with the speed reduced to a sufficiently low value by resistance or other means, it is extremely difficult to keep this speed uniform if the load varies through any considerable range.

At least four other distinctive types of slow motion, all dispensing with the starting motor, have been employed with electric drive in the past 20 years and some have shown merit which may lead to their reintroduction. These are:

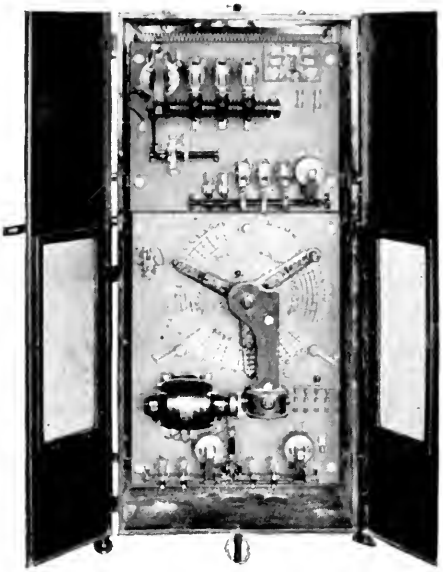


Fig. 8. A-c. Controller for Drive Shown in Fig. 6

- Direct-current motor with 3:1 or 4:1 field control and with armature shunted for threading speed.
- Direct-current motor with separate motor-generator set to supply a low voltage for use in giving a low speed to the main motor; the "teaser" system.
- Alternating-current or direct-current motor with double-reduction back gearing and mechanically operated friction clutch.
- Alternating-current or direct-current motor with double-reduction gearing, spur or internal, and magnetically operated clutch.

However, at this time the two-motor drive is nearly universal in this country.

The basic requirements of a newspaper press drive and control are as follows:

Reliability. Delay due to breakdowns are more costly in the press room of a daily paper than in almost any other line of manufacture. The loss of an edition may mean the rebating of thousands of dollars on advertising contracts. The motors must not fail. The control must not get out of order.

Proper Functioning. Even if the equipment does not fail or break down due to electrical or mechanical troubles, delay and expense may come from uneven acceleration, jerks or other improper operation. A paper break may tie up the press for a considerable time. Failure to run evenly at high speeds may force reduced speed and delay production. Improperly adjusted brakes may cause too quick a stop, or a stop not quick and smooth enough. Jerky starting or stopping may in time cause crystallizing and fracture of gear teeth on the press.

Safety. Perhaps this should be first on the list. Men are of greater value than machines. All modern electrical equipment, however, gives great regard to protection of operators from injury. A press drive and control requires, in addition to the usual protection, devices to prevent improper and unexpected starting, lock-out of the control while working on the press, warning signal at starting, quick stopping in emergencies, and automatic stopping on breaking of the web.

Economy of Operation. In a small newspaper office, whose edition can be run off in an hour or two, power consumption does not assume the importance it does in a big metropolitan daily with a series of editions which keep the presses running a large part of the day. Saving in paper waste by proper control is usually more important than small savings in power consumption.

First Cost. This comes last because, while first cost counts, no publisher can afford any other equipment than the best. On the other hand, the introduction of too many and too complicated relays and other devices in the control for protection, etc., may increase the cost beyond their worth, because these very devices may be unreliable and result in more trouble by their presence than by their absence. The simplest is often the safest and most reliable.

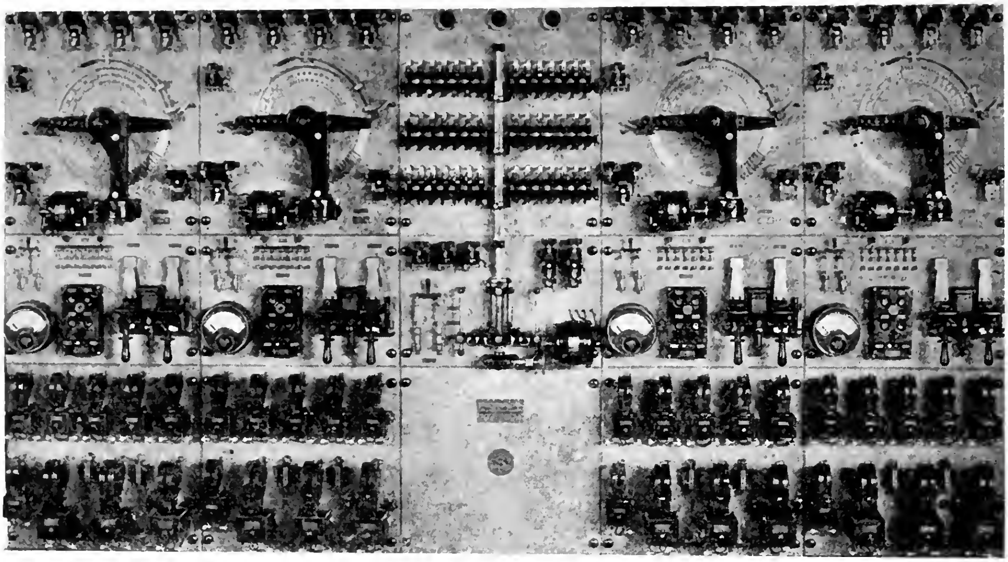


Fig. 9. Controller for Four Drives Operating a 12-unit Press

Controllers for Newspaper Presses

The driving and control equipment for a newspaper press include the following:

(1) The main driving motor.

(2) The starting motor.

(3) The reduction gearing between the two.

(4) The over-running clutch for disengaging the starting motor when the main motor takes hold.

(5) The base, pedestal, shaft, bearings, couplings, or other parts needed for the assembly of parts (1), (2), (3) and (4).

(6) The chain drive or gear drive between the main motor and press shaft.

(7) The controller which includes:

  (A) The main circuit disconnecting device, fused switch or circuit breaker, integral with the panel or separately mounted.

  (B) The contactors or magnetic switches for connecting or disconnecting the starting motor and main motor.

(C) The accelerating and retarding means: consisting of a series of stationary contacts for cutting out or cutting in resistances, as a contact-making arm or cross head is moved successively over these segments under the action of a pilot motor, solenoid, or gravity restrained by a dashpot. The contacts so established may act on resistance direct or may serve as pilot circuits for operating electro-magnetic switches to establish such resistance connections. Included in the accelerating means are the resistances which may be mounted on the back of the panel in the case of direct-current field resistances, or separately in frames mounted near the panel and connected thereto by asbestos-covered wires.

(D) The stopping means: including dynamic braking for direct current; solenoid brakes and "torque-motor" brakes for alternating current; and separate brakes on the press itself, which have been of four types, viz.: disc brakes on extensions of the press cylinders; shoe or band brakes on extensions of the impression cylinder shafts operated by torque motors mounted below the press or by compressed air through cylinder and pistons direct connected to the brake band; and band brakes acting under the influence of solenoids on brake wheels secured to the vertical shafts driving the press units.

(E) Protective devices, including:
Overload protection.
Under-voltage protection.
Protection against accidental starting.
Safety lock-out for the pressman working on the press.
Warning signal before starting.
Locking against increase in speed after a certain maximum has been reached.
Adjustable setting of maximum permissible speed.
Prevention against too rapid acceleration or retardation.
Automatic return of controller to "off" position after starting.
Prevention against connecting in main motor unless starting motor has started and come up to speed.
Device for stopping the motor and setting the brakes when the web breaks.
Protection against overtravel of the switch arm, and hence the attainment of a greater speed than desired for any given condition, quality of paper, etc.

Fig. 10. Push-button Station for Newspaper Press Control

(S) The push-button stations, located about the press, for inching, jogging, starting, low-speed, accelerating, slow-down, stopping, safety lock-out, and warning signal. The minimum number of buttons in any one station for a full automatic control system would appear to be four, and it should be unnecessary to resort to more than seven for the most complicated system.

The push-button stations and the wires connecting them up are an extremely important part of the system. The push-button mechanisms themselves must be very substantial as they are in constant use under none too dainty handling.

There are from four to nine wires in the conduits leading to the push-buttons. If any of these wires becomes grounded, or open-circuited, or if a short circuit develops between wires, the system may be temporarily inoperative. Hence, it is best to use none but the very highest grade of multiple conductor cable, thoroughly insulated, and well protected mechanically. If run in flexible conduit, the cable must be lead covered. Great care must be taken to prevent abrasion in pulling the wires in, and making connections. Great care must also be taken to prevent oil getting into the cable. Oil may run down the press frame, soak into the push-button station, and so into the wiring; or it may run into junction boxes below the press if the latter are not oil tight. Filling them with paraffin is a good precaution.

It is customary to provide an emergency push-button station, with an entirely independent wiring system direct from the controller, for use in case a failure occurs in the main system.

The Electron in Chemistry

PART III

By Sir Joseph John Thomson

Master of Trinity College, Cambridge, England

The first of this series of lectures appeared in our August issue. The present lecture deals with the Mechanism of Chemical Combination; Formation of the Double Layer; Active Molecules; Thieles' Theory of Partial Valencies; Kete-enol Change; Production of Light by Chemical Change and on Homologous Elements and Variable Valency. These lectures are reprinted by permission from the Journal of the Franklin Institute.—Editor.

The Mechanism of Chemical Combination

Let us in the first place consider chemical combinations between gases. That something more than collisions between the molecules of the reacting gases is required is clear, from the fact that gases like hydrogen and oxygen, hydrogen and chlorine (in the dark), which can form very stable compounds, can be mixed without any appreciable amount of chemical combination taking place at moderate temperatures. The test is a very severe one since at atmospheric pressure each molecule of oxygen in a mixture of hydrogen and oxygen would in one second collide with many million hydrogen molecules, so that even if only one collision in a million were to result in combination the rate of combination would be very great. A mixture of hydrogen and oxygen in the proportion of two molecules of hydrogen to one of oxygen can be stable, (*a*) when the gases are uncombined, and (*b*) when they are combined and the mixture exists as water vapor. The large evolution of heat observed in the transit from (*a*) to (*b*) shows that (*b*) has much less potential energy than (*a*). The fact that the gases can exist side by side without combination shows that the phase of high potential energy does not spontaneously pass to one of lower. We have many examples of this in ordinary mechanics. Thus the water in a mountain lake has more potential energy than it would have if it ran down into the valley, it does not do so because before it could get away work would have to be supplied to raise it above the level of the height immediately surrounding it. If a syphon is put into the lake this work is forthcoming and the water will run out. To enable a system to pass to a state of smaller potential energy may require the expenditure of a certain amount of energy and if this is not forthcoming the change will not take place. Thus, if a preliminary to the combination of hydrogen and oxygen were the dissociation of the molecules of these gases into atoms, the gases would not combine unless the very considerable amount of energy required for this initial stage were available. Now in the mixture of two pure gases the energy available is that due to the thermal agitation of the molecule; this at 0° C. is only about 1/30 of a volt per molecule, and is small compared with the changes in energy occurring in chemical processes which on the same scale would be represented by several volts. Thus we might expect that unless some source of energy besides that due to thermal agitation were available, the combination would not take place. In the case we have just been considering, that of the dissociation of electrolytes in solution, the main part of the energy required to separate the ions in the electrolyte came not from thermal agitation, but from that derived from the falling in of polar molecules, *i.e.*, from the energy of chemical separation of the polar molecule and the molecule of the electrolyte.

The effect of water vapor, whose molecule is strongly polar, on the combination of gases is well known. Thus, H. B. Baker showed that very carefully dried HCl and NH_3 would not combine, that the combination of H_2 and Cl_2 went on exceedingly slowly, even in strong sunlight, when the gases were carefully dried, while H. B. Dixon showed that electric sparks might be passed through a mixture of dry CO and O_2 without combination taking place. He also showed that other substances besides water vapor render possible the combination between CO and O, and it is probable that all polar molecules possess this property to a greater or less extent. Baker found that the effect of water vapor was not confined to combination if extended also to dissociation, for while ordinary ammonium chloride is dissociated to a very considerable extent when the temperature is raised to three or four hundred degrees centigrade, no dissociation occurs at these temperatures if the salt is very carefully dried.

When polar molecules, such as those of water or ammonia, are present, they may combine with the other molecules, forming aggregates in which, as in the case discussed in a previous lecture, there is a kind of incipient ionization, the atoms being more widely separated than in the normal molecule. The aggregate has a finite electrical moment and thus exerts much greater forces on neighboring molecules than the normal molecule. Let us represent these aggregates by $A\ (H_2O)_n$, $B(H_2O)_m$ when A and B represent molecules of the reacting gases. When two of these come together the work required to separate them may be so much greater than that required to separate AB that though A and B cannot by collision form a potent aggregate $A\ (H_2O)_n$ and $B\ (H_2O)_m$ are able to do so. After the aggregate has been formed the atoms loosened by the action of the polar molecules rearrange themselves so as to produce the system with the minimum potential energy. If, as the result of this rearrangement, the water is set free, it will be available for producing a further supply of the complex molecules. Even if only a small percentage of the molecules are in the complex state the rate of combination might be considerable, as the number of collisions made by a molecule under ordinary circumstances is so large. Thus to take the combination of gaseous HCl and NH_3 to form HN_4Cl as an example. If even only one molecule in a hundred thousand were in the complex state and if the combination only occurs when a complex molecule of HCl collides with a complex one of NH_3, these collisions will still be so numerous that something like one per cent of the HCl and NH_3 will combine per second. We see from this that to avoid appreciable combination the gases must be exceedingly dry, and that traces of water too small to be detected by other means might produce very marked effects on chemical combination.

On this view of chemical combination the rearrangement of the atoms takes place inside a complex formed with the polar molecules, thus no ions need get free. There is very strong evidence against the necessity for the existence of free ions in gaseous combinations; free ions make a gas a conductor of electricity and the conductivity due to free ions can be detected when the number of free ions is much less than one-million-millionth of the number of molecules. Many cases of chemical combination have been tested for electrical conductivity without any trace of it being detected. Thus L. Bloch[18] showed that many chemical actions which go on at moderate temperatures, such as the oxidation of nitric oxide, the action of chlorine on arsenic, the oxidation of ether vapor and so on, have no effect on the electric conductivity of the gases. I found, too, that even when the combination was as vigorous as that between hydrogen and chlorine in the light, no effect whatever was produced on the electrical conductivity of the mixture. Again dissociation at moderate temperatures such as that of nickel carbonyl at about 100° C. into nickel and carbon monoxide, or in the dissociation of arseniuretted hydrogen, is quite without effect on the conductivity. This is in accordance with the consequences of the theory.

There are, however, some cases in which free gaseous ions are produced by dissociation or chemical action. Thus Kalendyk[19] found that the vapor of potassium iodide was a conductor of electricity at temperatures above 300° C. if damp, but not when dry; this is a good example of the effect of water vapor. Another case investigated by Bloch (*loc. cit.*) is the oxidation of P_2O_3 to P_2O_5, which is also accompanied by an increase in electrical conductivity.

The efficacy of polar molecules is on this view due to their large electrostatic moment, which causes them to be strongly attracted by other molecules. Any systems, such as free electrons or gaseous ions, which give rise to strong electric fields, might be expected to promote chemical combination by processes similar to those which occur with water molecules.

Again, if the reacting gases were condensed on the surface of a piece of metal, or on the surface even of a non-metal or liquid, particularly if these substances were of special types, the molecules would find themselves in the presence of agents of the kind we are considering. At the surface of a metal there are mobile electrons, while the molecules at any surface can only be coordinately saturated in very exceptional cases. For when a new surface is produced by fracture some of the atoms which helped to "satisfy" the molecules left behind have been torn away, so that the molecules on the surface must be unsaturated and able to bind other atoms or molecules. The energy derived by the approach of a molecule to the unsatisfied molecules at the surface of the solid or liquid may be used to separate the atoms in the approaching

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[10] *Annales de Chimie et de Physique*, 22, pp. 370, 441; 23. p. 28.

[19] *Proc. Roy. Soc.*, A90, p. 638, 1914.

molecule, in just the same way as the energy due to the approach of a polar molecule helped to separate them. Thus the molecules of a gas condensed in a layer on a surface will be exposed to influences very similar in character to those to which they would be exposed when combined with water molecules, and we may expect to find that the connection between these atoms gets so loose that these are able to rearrange themselves and form new compounds.

The layers condensed on a surface will in many respects be in a more favorable condition for entering into chemical combination than the free molecules of the gas, even if these are supplied plentifully with water molecules. For the molecules in the surface layer will be crowded together and kept in close contact; they will thus be in a situation particularly favorable for the rearrangement of their atoms.

The effect of metal surfaces in promoting chemical combination is shown by the combination of hydrogen and oxygen produced by platinum black, by the synthesis of ammonia in the Haber process, by the effect produced by metals when in the colloidal state, by the Sabatier-Senderens method, wher many changes in organic compounds are produced by passing them along with hydrogen over finely divided nickel or certain other metals at a high temperature. Another instance is the effect produced by the walls of the vessel in which the reacting gases are contained; many examples of this are given by Van t'Hoff in his studies on chemical dynamics.

It is possible that water in addition to the effect it produces by the individual molecules may produce an additional effect by forming small drops, which in the aggregate might have a very large surface, on which the gases might condense.

We can get some very direct evidence as to the conditions at the surface of separation of gases, liquids and solids by the study of the very interesting cases of electrifications produced by the bubbling of gases through liquids, by the splashing of liquids against solid surfaces, and the motion under an electric field of bubbles of air and colloidal particles through liquids When gases bubble through certain liquids of which water is a conspicuous example, the gases after they emerge from the liquid are found to be electrified. The liquids which give rise to this electrification are those which possess considerable electrical moments i e, they are those which, as we have seen, have the property of forming complex compounds with compounds which are already electrically saturated. The amount, and even the sign of the electrification produced by bubbling, is very sensitive to small changes in the composition of the liquid. Thus air bubbling through pure water emerges with a negative charge, but if a small quantity of HCl or H_2SO_4 be added to the water, the electrification of the air becomes positive. The electrification is dependent upon the breaking of the liquid film when the air bubble escapes from the fluid. No electrification is produced by blowing a current of air along a water surface or by stretching, without breaking, a liquid film. A similar dependence upon the composition of the liquid is shown by the motion through a fluid of small particles or air bubbles under an electric field, a phenomenon which is sometimes called cataphoresis. The addition of acids and salts, especially if these contain elements of high valency, produces a great effect on the velocity with which the bubble moves through a liquid under a constant electric field. Cataphoresis is more amenable to mathematical treatment than electrification by bubbling and the mathematical theory has been worked out by v. Helmholtz and Lamb on the supposition that there is a double layer of electricity, one layer being positive and the other negative, at the surface between the bubble and the liquid, and that one layer is attached to the liquid, the other to the bubble or colloidal particle. If v is the velocity of a particle under an electric force X, η the coefficient of viscosity of the liquid, σ the surface density of the electric charge on either layer, d the distance between the layers, then according to v. Helmholtz

$$v=\sigma dX/\eta \tag{29}$$

so that the measurement of the velocity would at once give us the potential difference at the surface. Lamb has given very strong reasons for thinking that this relation is not sufficiently general and is based upon suppositions which are not likely to be valid when, as in this case, we are dealing with distances which are of the order of atomic distances; he finds instead of (29) the equation

$$v=\sigma lX/\eta \tag{30}$$

where l is a length dependent on the liquid and on the nature of the particle. As l is not known, we cannot claim that the use of the v. Helmholtz formula gives more than the order of the surface density; in some cases, however, where it has been possible to measure the potential difference between the particle and water, this has been in fair agreement with the value deduced by Helmholtz's equation. It will be noticed that according to either formula the velocity of the particle is independent of its size, provided σd and σl are unaltered. This has been verified by several observers, among others by Burton[20] and McTaggart.[21] In water, air bubbles and some solid particles move as if the negative charge were on the particle, and it is remarkable that, in spite of great variations in the character of the particle, the changes in the potential difference are comparatively small. This is shown in the following table taken from Burton.[22] The potential difference ϕ has been calculated from the v. Helmholtz equation assuming

$$\phi = 4\pi\sigma d / K$$

where K is the specific inductive capacity of water.

Substance	Potential Difference in Volts Deduced by Helmholtz's Equation
Lycopodium	–.035
Quartz	–.042
Air bubbles	–.056
Arsenious sulphide	–.031
Prussian blue	–.056
Gold (Bredig)	–.030
Platinum (Bredig)	–.028–.034
Silver (Bredig)	–.033
Mercury (Bredig)	–.035
Bismuth (Bredig)	+.015

We see from this list that for many substances the difference of potential between the two layers is about 1/30 of a volt; this is very nearly the potential difference through which an electron must fall at room temperatures to acquire an amount of energy equal to that possessed by a molecule of gas from its thermal agitation. Thus a charged atom at the double layer would possess by thermal agitation an amount of energy comparable with that required to detach it from the double layer. We should expect that a limit to the potential difference between the two layers must be imposed by the necessity of one layer being able to move freely relatively to the other. If, for example, the double layer were formed by positively and negatively charged atoms in the same molecule it could not produce cataphoresis unless some source of energy sufficient to dissociate the positive from the negative parts were forthcoming. If this energy has to come from thermal agitation, the positive and negative parts must have been driven so far apart that the energy required to separate them is of the order of the mean kinetic energy of a molecule due to thermal agitation, which at 0° C. is about 1/30 of a volt. The energy required to detach a charge from the double layer is proportional to the potential difference between the layers. Thus the energy available from thermal agitation may be a most important factor in determining the value of the potential difference in the effective double layer.

The Formation of the Double Layer

Polar molecules, such as those of water, have, as we have seen, the power of forming molecular compounds in which oppositively charged atoms are separated and put into a condition in which they can be easily detached from each other. These compounds are of two types, in the first symbolized by such a case as $[Me.4H_2O.(OH)_2]H_2$, the effect of the formation of the complex compound is to give a charge of negative electricity to the substance with which the water is in contact and to put two positively charged atoms into a condition in which they can easily be detached from the substance. The formation of a compound of this type would produce a double layer with the positive part in the water and the negative on the substance. This is the type of double layer formed at the surface of colloidal particles of platinum, gold, silver, quartz or air bubbles. The other type of complex compound is that symbolized by $[Ca.4H_2O_1]Cl_2$, here the water molecules drive out the negative constituent from the original compound and give to the system surrounding the central atom a positive charge. If a substance of this kind were formed there would again be a double layer, but in this case the negative part of it would be in the water, the positive on the substance in contact with the water. This is the type of double layer formed at the surface of colloidal particles of ferric hydroxide.

The case of a gas bubble in water is an interesting one in which the evidence on some points is somewhat conflicting. McTaggart[21] found that the velocity of bubbles of hydrogen was the same as that of oxygen bubbles indicating that the potential difference was independent of the nature of the gas, and that the gas did not take part in any chemical reaction. Alty, who has recently been making experiments on this point in the Cavendish Laboratory, finds that considerable variation in the velocity of the bubbles is produced in

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[20] "Physical Properties of Colloids," 2nd Edition, p. 136.
[21] *Phil. Mag.*, 27, p. 297 (1914).
[22] "Physical Properties of Colloids," p. 135.

some cases by changing the gas. The view that oxygen may take part in chemical reactions with water is supported by the observation frequently recorded but first made, I think, by Bellucci,[23] that the air in the neighborhood of waterfalls, where there is a great deal of splashing, contains abnormally large quantities of ozone. Under the action of the water molecules ozone may be formed and negatively electrified ozone form the coating in the gas of the double layer.

We should expect that there would be a double layer at a surface separating water from its own vapor. Hardy and Langmuir have pointed out that the molecules at a liquid water surface are polarized, *i.e.*, the number of molecules which have their positive ends at the top is not the same as the number with the negative end. Thus, suppose the majority of molecules had the negative ends, *i.e.*, the oxygen atom, at the top, the oxygen atoms are not coordinately saturated and may combine with the molecules of water vapor to form compounds of the type $[O.H_x]\,(OH)_x$: This would give rise to a double layer with the positive half in the water, the negative one in the bubble. Experiments are in progress at the Cavendish Laboratory to see whether any evidence can be obtained of a double layer when water is in contact with nothing but water vapor.

The formation of the double layer gives a supply of positive and negative ions at the surface of an air bubble in water. Just before the bubble emerges from the water this surface has a considerable area. It is reduced to very small dimensions after the bubble emerges. Thus the emergence of the bubble involves a considerable and very abrupt contraction of the surface and of the double layer associated with it. The double layer will be violently distorted and it does not seem surprising that some of the ions in the layer on one side should not have time to combine with those on the other before they are carried away by the air. Only a very small fraction of the ions in the double layer get liberated when air bubbles through water. Assuming v. Helmholtz's formula, we can calculate from the velocity of the bubble the quantity of electricity per unit area of each layer. Assuming that the distance between the layers is 10^{-8} cm., McTaggart (*loc. cit.*) found that this density was 4×10^{-5} coulombs per square centimeter. If all the water molecules had been polarized, *i.e.*, if all the OH ions of the water molecules were next the surface and if the distance between two molecules of water on the surface were the same as that in the interior, *i.e.*, 3.09×10^{-8} cm., the density would be about 1.7×10^{-4} coulombs per square centimeter, about four times greater. On one layer of a bubble 7.8 mm. in diameter the charge on either layer would be 7.6×10^{-5} coulombs. Simpson[24] found that when a drop of this size struck against a plate the amount of electricity set free was 2.8×10^{-12} coulombs, *i.e.*, only about one thirty-millionth of the charge on the layer. We conclude from this that only an exceedingly small fraction of the water molecule at the surface of an air bubble or drop of water is ionized by the bursting of the bubble or the splashing of the drop.

When air bubbles through water sone ions become free, there are other types of experiments when, though there is a separation of positive and negative electrification, few if any ions get free. The Armstrong hydro-electric machine is a case in point. Here small drops of water are carried by a jet of steam through a tube with great velocity. In their passage through the tube the drops strike against the sides and the tube becomes negatively, the drops positively, electrified. Here the separation of the positive and negative electrification is the principal effect and not the liberation of free ions. We have supposed that at the surface of a drop of water there is a double layer, the negative part, OH ions, in the air and the positive part, H ions, in the water. When the drop strikes against the tube the OH ions combine with the material of the wall of the tube forming those molecular compounds we have been considering in this chapter. When the drop rebounds from the wall of the tube it will tend to take the H_+ ions away with it, while the walls of the tube will hold the OH_- ions. The ions will be separated by the kinetic energy of the drops. The ions will not, however, get free; the positive ones will be on the water drops and the negative ones on the walls of the tube. This is a particular case of

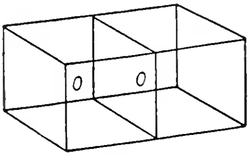

Fig. 35

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[23] *Ber. Deutschen Chem. Gesell.*, 8, p. 905 (1875).
[24] *Phil. Trans.*, 209A, p. 379 (1909).

electrification by friction, and it is evident that the formation of double layers must be of vital importance in that phenomenon.

Active Molecules

We have hitherto considered the way in which chemical combination was promoted by polar molecules and by active surfaces, the energy necessary for the preliminary separation of the atoms in the reacting molecules before their final readjustment to form the molecules of the new compound coming from the potential energy of separation of the polar molecules and of the reacting molecules before combination. We have seen that the kinetic energy of thermal agitation is inadequate for this purpose. Though the influence of polar molecules on chemical combination is undoubtedly very great, the evidence does not, I think, warrant the conclusion that all chemical combinations are dependent upon their agency. The combustion of carbon bisulphide, of cyanogen and of certain hydrocarbons in oxygen appears to be unaffected by the presence of traces of moisture.[25] The question arises, what is the mechanism by which the combination can be brought about, when the energy arising from polar molecules is not available, and when that due to thermal agitation is too small to split up the molecules of the reacting gases into atoms? The electron theory indicates a way in which certain molecules could be put into a chemically active state without separation into atoms by an expenditure of energy much less than would be required for that purpose. Consider, for example, a molecule of oxygen, its neutrality is attained by the arrangement of its electrons into two octets, to obtain these two the utmost economy in construction must be observed and the octets have to have four electrons in common. Let the electrons in the molecule be displaced so that the cells surrounding the atoms have no longer four electrons in common, suppose, for example, that they have only two in common, then since there are only twelve electrons available there can only be seven electrons in each cell, and each atom will be surrounded by only seven electrons instead of by eight. Now the cell of seven electrons is not saturated and will be chemically active, though it will not be so unsaturated as the free oxygen atom which is only surrounded by six electrons. To move the electrons so as to change the arrangement of electrons from that corresponding to the inactive state represented by Fig. 35 to that of the active state represented by Fig. 36 would require far less energy than to separate the atoms, so that the necessary amount may be derivable from thermal agitation at temperatures far below that required to separate the atoms.

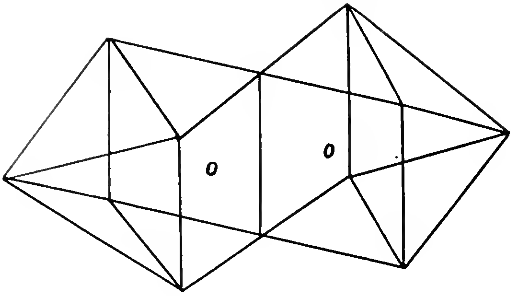

Fig. 36

I think this conception of the active molecule has an important bearing on the combination of explosive mixtures such as those of oxygen and hydrogen; these gases explode at temperatures as low as 600° C. where the energy of thermal agitation is quite insufficient to split the oxygen molecules up into atoms. Indeed, direct experiments on the relation between temperature and pressure have shown that there is no appreciable dissociation of the molecules of oxygen at 1700° C. If, however, the work required to make the molecule active in the manner described was that corresponding to thermal agitation at a lower temperature, say 600° C., then if in any region of a mixture of the explosive gases the temperature reaches this value, the oxygen molecules will become active and combine with the hydrogen, the heat developed by the combination will raise the temperature still further and the hot molecules will travel out with energy sufficient to make the molecules of oxygen against which they strike active. This will lead to further combination and a further development of heat and combination will spread throughout the mixture.

As there is no dissociation of the molecules into atoms, the process of making the oxygen molecules active will not change the pressure in pure oxygen.

There is direct experimental proof that the molecule of oxygen can be put into the active state. When we use the method of positive rays we find that oxygen is one of the few molecules, as distinct from atoms, that can occur with a negative charge. If the oxygen

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[25] H. B. Baker, *Proc. Manchester Phil. Soc.*, 53, No. 16.

molecule could only occur with its electrons arranged as Fig. 35, it could not receive a negative charge, because there is no room for an electron in the octets. It could, however, receive such a charge if the electrons were arranged as in Fig. 36 because there is room for an electron on each of the septets.

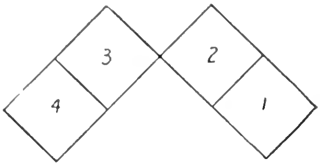

Fig. 37

The fact that a particular atom or molecule can be negatively charged shows that it can be in stable equilibrium after receiving an additional electron, so that in the neutral state it is unsaturated and chemically active.

The arguments we have used about the oxygen molecule will apply to any arrangement of electrons where there are two octets with four electrons in common. This arrangement occurs when we have two atoms connected by a double bond—it occurs, for example, in carbon compounds whenever there is a double bond between two carbon atoms, $C=C$, it so occurs in the combination $C=O$, though not in $C-O-H$.

Thieles' Theory of Partial Valencies

This conception of the active molecule leads in many cases to the same results as Thieles' theory of partial valencies. Thus to take the case which led to the theory. It was found that a compound where the carbon atoms are arranged according to the scheme $\overset{\diagdown}{\underset{\diagup}{C}}=\underset{|}{C}-\underset{|}{C}=\overset{\diagup}{\underset{\diagdown}{C}}$, where two double bonds are separated by a single one, when it forms additional compounds does so by adding the new atoms to the carbons at the *ends* of the chain. On our view the distribution of the electrons in the compound is represented in Fig. 37.

There are four octets, 1, 2, 3, 4; 1 and 2 and also 3 and 4 have four electrons in common, 2 and 3 only two. Suppose all the carbon atoms get put into the active condition. The octets with four electrons in common will become septets with two electrons in common and the system will be a chain of four septets (Fig. 38), where the septets are represented by triangles, each having two electrons in common with its nearest neighbor. To make this change in which all the carbon atoms have been made active requires the expenditure of a certain amount of energy; an expenditure of a smaller amount will be sufficient to make a part of them active. To find the change which will require the least energy, we notice that if any adjacent pair of septets were to revert to a system with four electrons in common, the new system would have less potential energy than that shown in Fig. 38, and would require less energy to be expended to derive it from the original system.

The work required for this change would be the work required to convert the system (Fig. 37) into the system (Fig. 38), minus the loss of potential energy when an adjacent pair of septets reverts to two octets with four electrons in common. Thus the system which will require the minimum work will be the one when the pair which reverts is the one for which the loss of potential energy on reversion to octets is greatest. This pair will be the one which is most symmetrically placed, *i.e.*, the central pair. Thus the active configuration which requires the least expenditure of work is that represented in Fig. 39, where the end cells are septets and active. As these cells are active, additions will take place at them, and the central carbons will be connected by a double bond.

Keto-enol Change

The same reasoning will apply where the double bond is between a carbon and an oxygen atom (Fig. 40). Thus in the compound $O=\underset{|}{C}-\underset{\wedge}{C}-H$, the distribution of electrons is that represented in the figure, if the two octets with four electrons in common are made active, the active oxygen units with the neighboring atom of H, the hydrogen coming away from

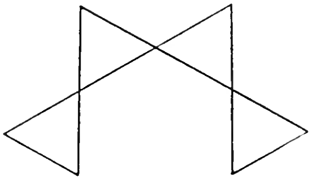

Fig. 38

C_2 with its electron; this completes the octet round O, leaving septets round C_1 and C_2 with two electrons in common; these revert to the more stable arrangement of the same number of electrons, *viz.*, two octets with four electrons in common, and we have thus the compound

$$OH-\underset{|}{C}=\underset{\wedge}{C}$$

this is known as the keto-enol change. It only takes place when one of the atoms attached to C_2 is that of an electronegative element; the reason for this follows from the same considerations as those previously given to explain the effect of introducing electronegative groups into hydrocarbons.

The same principles will apply to a smaller extent when two octets have only two electrons in common, for if the electrons were displaced so that the cells had only one electron in common, one of the atoms would become active and could enter into chemical combination. Thus, if the electrons in a chlorine molecule get displaced so that the cells have only one electron in common instead of two, one of the cells will become active and can combine with hydrogen. The energy required to displace the electrons need not come from the energy of thermal agitation, it might come from light if that were absorbed by the molecules.

Production of Light by Chemical Change

Many chemical reactions involve an increase or a decrease in the number of electrons grouped round some of the atoms; thus, for example, if an atom of hydrogen combines with one of chlorine to form HCl, after combination the chlorine atom is surrounded by eight electrons, whereas before it was surrounded by only seven, thus the reaction has resulted in an electron falling into the layer round the chlorine atom; this atom may be regarded as coming from the hydrogen atom. On the other hand, when HCl dissociates into H and Cl the chlorine ion loses an electron, while the hydrogen ion gains one. We shall use the term oxidation for the process by which the atom of an electronegative element gains an electron and becomes negatively charged since ordinary oxidation is a process of this kind, and reduction for the process by which a positively electrified ion of an electropositive element receives an electron and becomes neutral.

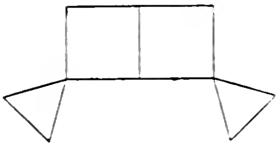

Fig. 39

Thus, in oxidations an electron falls into the zone round the atom of an electronegative element; in reductions an electron falls into the zone round the atom of an electropositive one. From the study of the luminous effects in the discharge of electricity through gases we are led to the conclusion that the capture of an electron by an atom results in the emission of light, and from the quantum theory it would follow that the frequency of the light would be proportional to the potential energy lost when the electron falls into the atom, or what is equivalent, to the work required to remove an electron from the negatively electrified constituent of the compound in the case of oxidation or from the neutral atom in that of reduction. Thus we should expect that both oxidation and reduction would be accompanied by the emission of light; it may be that the rate at which the chemical processes go on is so slow that the energy in the light is not sufficient to make it apparent, or again, that the wave-length of the light is not within the range of the visible spectrum. The production of light by chemical action is a well-known phenomenon. In addition to the conspicuous cases of flames where the temperature is high, there are many examples of luminosity occurring at moderate temperatures; the luminosity of phosphorus when oxygen passes over it is one example; then there is the luminosity of sulphur when heated to about 300° C. in the presence of oxygen, the light given out by the glowworm and by the animalculae which cause the phosphorescence of the sea. Linneman found that fresh surfaces of sodium or potassium are luminous in the dark until they get covered by a coat of oxide. This production of light is, I think, the cause of the emission of electrons in the dark from the alloy of sodium and potassium when exposed to various gases which I observed many years ago and which has been investigated very fully by Haber. If chemical action went on between the gases and the NaK alloy,

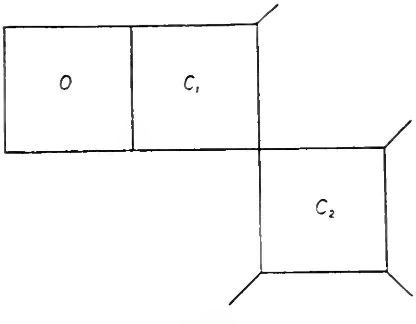

Fig. 40

light would be given out, and as the alloy is very photoelectric, electrons would be given out by the surface of the alloy. The seat of the light is at the surface of the alloy so that, although the light might not be intense enough to be visible at molar distances, yet at the atomic distances which separate it from the alloy its intensity might be sufficient to produce very considerable effects. Again, since in oxidations the origin of the light is in the electronegative elements, we should not expect to find in light due to oxidation the spectrum of the electropositive element. It has long been considered remarkable that the spectrum of hydrogen is not visible in flames or in light produced by chemical means, though it is so easily produced by the electric discharge. This is just what we should expect if the chemical reactions were of the type of oxidations; to have a chance of getting the hydrogen spectrum the process should be a reduction. Thus, for example, in the partial dissociation of hydrodic acid, when there is equilibrium between the formation of HI and its dissociation into H and I, the combination would give rise to the spectrum of HI with the iodine as the source of light, the dissociation might give the hydrogen spectrum. It is to be noted that the spectrum of a molecule may vary with the atom in that molecule which is excited. Thus to take as an example $COCl_2$, the spectrum emitted due to the fall of an electron into the oxygen atom would not be the same as that due to the fall of one into the chlorine atom. We have in considering the type of light emitted to consider not merely the atom into which the electron falls, but also the method in which it falls. Thus to take a case in which we have very vigorous reduction going on, that of the liberation of hydrogen from the cathode when strong currents pass through acidulated water. Since the hydrogen atoms which come off are neutral, the hydrogen ions which were positively electrified must each have received an electron and so might be expected to have given out light. I am not aware, however, that anyone has observed any luminosity in the neighborhood of the cathode during the electrolysis of acidulated water. Nor need we, I think, expect it; we have already seen reasons for thinking that hydrogen ions in water have attached to them a number of water molecules, the negative ends of these molecules being turned towards the hydrogen ion. The effect of these negative charges is to diminish very materially the attraction of the hydrogen ion on the negative electron, so that when the electron falls into the ion it will do so with very much less energy that it would in the absence of the water molecules; as the energy is so much less, the intensity of the light and also its frequency will be greatly diminished, so that not only will the light be feeble, but also probably far away, on the red side of the visible spectrum.

On Homologous Elements and Variable Valency

Homologous Elements.—The valency of an element depends according to these views on the number of electrons in the outer layer rather than upon the total number of electrons in the atom. We have supposed that the electrons in the atom are arranged in a finite number of layers, the members of each layer being approximately at the same distance from the center of the atom. As we pass from the atom of one element to that of the element next in order of atomic weight, we have to provide for the accommodation of one more electron in the atom. If the additional electron joins those in the outer layer it will give rise to an atom of an element of different valency and with very pronounced difference in chemical properties. If, however, the electron finds accommodation in one of the layers below the surface, the element corresponding to this atom will have the same valency as the first and will resemble it in chemical properties more or less closely according as the layer on which the new electron settles is near to or far from the center of the atom. Thus we might have a graduated series of elements differing in atomic weight; the properties of some—those with the additional electrons in the layers close to the center differing so little from those of some element of smaller atomic weight in the series that the two might with propriety be regarded as isotopes. The difference in properties will increase though the valency remains unaltered, as the electrons find a place in layers nearer the surface until finally we come to the element where the additional electron has got to the outer layer; here there is a change in the valency and a marked alteration in the chemical properties. We are thus led to expect the existence of groups of elements possessing very similar properties; in some cases the chemical properties might be so similar that the elements would not be separable by chemical means and would be classed as isotopes; in others the differences would be large enough to enable the elements to be isolated by chemical processes. Examples of such groups are the iron, nickel and cobalt group, the ruthenium, rhodium and palladium group, the large group of the rare earths and the iridium platinum group. Inside these groups, increase in atomic weight is not accompanied by change of valency; outside them, it is.

In considering the way in which a definite number of electrons will arrange themselves round a central charge, there are two influences of predominating importance: The first of these is the tendency of the electrons to get as close to the central charge as is consistent with the stability of the layer, *i.e.*, to have as many electrons in the innermost layer as the central charge can hold in stable equilibrium, and then as many in the second layer as the central charge when surrounded by the first layer can hold in stable equilibrium, and so on. This disposition will make the potential energy due to the forces between the positive nucleus and the electrons as small as possible. The potential energy due to the forces between the electrons has next to be considered. This will diminish as the distances between the electrons increase and will tend to make the electrons in the various layers arrange themselves so that their figures are similar, or at any rate have the same kind of symmetry about the center. This latter tendency would, if it prevailed, cause a new electron if added to an atom already containing a number of electrons either to go to the outer layer, or if that were full, to make the beginning of a new outer layer. The tendency to get as close as possible to the center would, on the whole, make for the retention of the electron by one of the inner layers.

We should expect that we could not go on increasing the number of electrons without reaching a stage where a new electron would stay in the inner layers. If so, its influence on the chemical properties would be very slight and the new element would be very similar to the old. The addition of an electron to one of the inner layers would alter the nature of its symmetry round the center and make it different from that of the other layers; as the different layers like to have the same kind of symmetry, when one layer has got a new electron the other will try to get one, too, so that when once the absorption of electrons by the inner layers has begun it will continue as the next few electrons are added to the atom. When each layer has received an electron, we may expect the next electron to come to the surface, giving rise to an element whose properties are markedly different from those of the elements which just preceded it. Thus the homologous elements might be expected to occur in groups and inasmuch as in the elements inside the group some of the layers have one kind of symmetry and others a different one, the distribution of electrons inside the atom of elements in a homologous group is irregular and does not possess the uniformity or regularity possessed by elements outside the group where the electrons in the inner layers have adjusted themselves so as to produce a high degree of symmetry.

Varying Valency.—We have been considering cases where different elements have very similar chemical properties, although they contain different numbers of electrons, where, in fact, we have variations in the number of electrons in the atom without much alteration in the chemical properties. The question naturally arises whether we might not have also variation in the chemical properties without alteration in the number of electrons, and whether the existence of some elements which have more than one kind of valency is not a case in point. Ferrous and ferric iron have different properties, so have cuprous and cupric copper. As the elements can pass backwards and forwards between the *-ous* and the *-ic* states, if these states correspond to two different configurations of the same number of electrons, these configurations must be such that by suitable chemical or physical processes they can pass from one form to the other. We have already seen that there are frequently more ways than one of arranging in stable equilibrium a given number of electrons round a central positive core. If these arrangements are to explain the difference between the *-ous* and *-ic* states of the elements, they must differ in the arrangement of the outer layer (*a*) because unless they did so there would not be sufficient difference in the chemical properties in the two states, and (*b*) because if the difference was only in the inner layers we could not affect these sufficiently by ordinary chemical operations to cause one configuration to pass into the other.

We should expect, I think, to find forms of the same kind of atom differing in their outer layers in those elements which are either in a group of homologous elements or in their immediate neighborhood. For in the atoms of such elements an electron hesitates, as it were, whether to go to the surface or to stay in one of the inner layers, *i.e.*, it hesitates between two different configurations. It is reasonable to suppose that by suitable influences at the surface the electron might be induced to take one course or the other and thus confer one valency or another on the atom of which it is an occupant. Now it is remarkable that many of the elements which are most conspicuous for the variability of their valency are either in the homologous groups or in their immediate neighborhood. Take, for example, chromium and manganese, which are the next neighbors of the iron groups, each of these shows great variations in valency in its different compounds, then molybdenum, the next neighbor to the ruthenium, rhodium and palladium group forms the series of chlorides $MoCl_2$, $MoCl_3$, $MoCl_4$, and $MoCl_5$; again tungsten, the next neighbor to the platinum and iridium group, forms the four chlorides WCl_2, WCl_4, WCl_5 and WCl_6, and nearly, if not quite, all of the elements in the homologous groups themselves form more than one series of salts. The electrons in the outer layers of elements of this type seem to be in a peculiarly sensitive condition and can move from one layer to another without much expenditure of energy.

The number of electrons which can be held in stable equilibrium in a single layer by a positive charge increases with the charge. Thus, though an inner layer of eight might be as many as the positive charge possessed by the lighter elements could stabilize, yet the heavier elements with their large positive charges might be able to stabilize more than this number. We should thus expect that at some stage in the list of elements the number of electrons in the inner layers would increase, that while when we pass from one element to the next and the number of electrons in the atom increases the additional electron stays in the inner layer instead of going to the one on the outside of the atom. When this process begins the change from atom to atom will not be the addition of an electron to the outer layer, but a reorganization of the distribution of electrons in the interior of the atom. The properties of the elements indicate that this process begins soon after passing calcium. To illustrate the point, I will take the series of elements beginning with titanium and consider the arrangement of electrons in it and the neighboring elements. I do not lay any stress on the actual numbers of electrons assigned to the inner layers; the determination of these would require much further investigation, both theoretical and experimental.

Titanium.—The distribution of electrons, if it followed the same course as in the lighter elements, would be represented by 2, 8, 8, 4, the figures representing the number of electrons in the different layers starting from the inside; the four electrons in the outer layer would make the element quadrivalent. The existence of the tetrachloride $TiCl_4$ shows that this distribution is one which occurs in nature. In addition to the tetrachloride there are the chlorides $TiCl_3$, $TiCl_2$, showing that forms of the titanium atom exist in which there are respectively one and two more electrons in the inside than in quadrivalent titanium, the distribution of electrons in the tautomeric forms may be represented by 2, 9, 8, 3, and 2, 10, 8, 2, respectively.

Vanadium.—If the electrons had followed the normal course, the arrangement of the electrons would be represented by 2, 8, 8, 5, and the element would be pentavalent. Vanadium is said to form a pentafluoride VF_5, so that this configuration would seem to exist. Vanadium forms chlorides VCl_4, VCl_3, VCl_2, in which the inner layers of the atom must contain respectively one, two and three electrons more than the preceding case; thus we have atoms in which the arrangements are 2, 9, 8, 4; 2, 10, 8, 3; 2, 10, 9, 2, respectively.

Chromium.—If the electrons followed the normal course the arrangement would be 2, 8, 8, 6, and the element would be hexavalent; the compound CrF_6 shows that this type exists. Chromium forms the chlorides $CrCl_3$, $CrCl_2$, so that in addition there are atoms of the type 2, 11, 8, 3; 2, 12, 8, 2, respectively.

Manganese.—The normal arrangement would be 2, 8, 8, 7. The fluoride MnF_7 shows that this type exists. There are in addition the fluorides MnF_4, MnF_3, MnF_2, corresponding to atoms of the type 2, 11, 8, 4; 2, 12, 8, 3; 2, 12, 9, 2.

Iron, Nickel and Cobalt.—From the similarity of these elements we infer that the distribution of electrons only differs in the inner layer. Their halogen compounds are all of the type $FeCl_2$ or $FeCl_3$; suggesting the following distribution of electrons:

Fe	2, 12, 10, 2. 2, 12, 9, 3
Ni	2, 13, 10, 2. 2, 13, 9, 3
Co	2, 14, 10, 2. 2, 14, 9, 3

Copper.—The halogen compounds are of the type $CuCl$, $CuCl_2$, indicating atoms with one or two electrons, respectively, in the outer layer, corresponding to distribution of electrons represented by 2, 14, 12, 1; 2, 14, 11, 2.

The normal process by which, when we pass from one element to the next in order of atomic weight, the new electron goes to the outer layer seems to be resumed after passing copper, thus we have zinc with two electrons in the outer layers; gallium with three; germanium with four; arsenic with five; selenium with six; bromine with seven, and krypton with eight.

Thus we see that as we proceed up the list of elements we may expect to meet with a batch of elements in whose atoms the electrons change from one tautomeric distribution to another with but little expenditure of energy. In this batch the ordinary progress of valency with atomic weight is interrupted, and the valencies are variable. On passing through the batch the regular sequence is resumed, the series goes on and ends with eight electrons on the outer layer, while the next series begins with one in that layer.

Paramagnetism.—One very conspicuous feature of the elements from titanium to copper is that they are strongly paramagnetic. The quality of paramagnetism would on several theories depend on a want of symmetry in the arrangement of the electrons in the atom. This would be the case, for example, in Parson's theory of the ring electron; it would also follow from the law connecting electrostatic and magnetic force which I suggested some time ago.[26]

If want of symmetry in the distribution of electrons is essential for paramagnetism, we can understand why it is confined to elements such as those we are considering, where the arrangement of the electrons in the inside of the atom may change, not merely from element to element, but even in a particular element under different external conditions. Outside such a group of elements the arrangement of the inner electrons does not change from element to element, it is very stable, and thus has probably a high degree of symmetry. It would, from this point of view, be interesting to test the magnetic qualities of compounds like Cr_6F and MnF_7, in which the readjustment of the inner electrons has not taken place.

The researches of G. Wiedemann, Quincke, Townsend, Pascal, Weiss, Kamerlingh Onnes and others on the relation between magnetic properties and chemical composition have brought to light a great number of very striking phenomena, which are very diverse and in some cases anomalous, their very diversity, however, renders them all the more suggestive.

For salts in solution, and the same seems to be true for salts in the dry state, especially if these contain water of crystallization, the value of k, the coefficient of magnetization, *i.e.*, the quotient of the induced magnetization by the magnetic force, depends upon whether the metal is in the *-ous* or *-ic* state, but does not depend upon the acid radicle with which it is combined. Thus if a solution contains a definite amount of ferric iron the value of k will be determinate, it does not matter whether the dissolved salt is ferric chloride, ferric sulphate or ferric nitrate. The same is true for the ferrous salts; again the value of k depends only on the quantity of ferrous iron, but the value of k for the same weight of iron will depend upon whether the iron is in the ferrous or ferric state. Thus if W is the weight of iron in a cubic centimeter—

$$10^7 k = 2660\,W - 0.7 \text{ for ferric salts.}$$
$$10^7 k = 2060\,W - 7.7 \text{ for ferrous salts.}$$

In such salts as ferrocyanide of potassium where the iron appears on the negatively electrified part of the molecule, thus $\overset{+}{K_4}(\overset{-}{Fe}\,CN_6)$, the compound is not paramagnetic at all, but slightly diamagnetic. The ferrocyanide $K_3\,(FeCN_6)$ is slightly paramagnetic, although the paramagnetism is very small in comparison with that of the ferrous or ferric salts. Similar results are shown by the magnetic metals Cr, Mn, Ni, Co. Copper itself is diamagnetic as are also the cuprous salts; the cupric salts, however, are magnetic. The oxides and sulphides of the magnetic elements show large variations in their magnetic properties, thus magnetite Fe_3O_4, which is regarded as a compound of FeO and Fe_2O_3, is much more magnetic than either of them, and a similar statement is true for the corresponding sulphur compounds. Again variation in the temperature may produce great changes in the magnetic properties of an element, thus four types of iron, α, β, γ, δ, have been detected by Osmond and other workers; these pass from one into the other when the temperature passes through definite stages, and each of these types of iron has characteristic magnetic properties. In discussing the meaning of these results we must remember that on the view that paramagnetic properties are due to the setting of magnets, or their equivalents, under the action of a magnetic force; the magnetization, unless the field is intense enough to produce saturation (a state of things which is not attained with solutions), will depend upon two quite distinct things: (a) The resultant of the moments of the magnets; (b) the restoring force which tends to keep the magnets in the position of equilib-

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[26] *Phil. Mag.*, 37, p. 419.

rium. A substance may have a small coefficient of magnetization either because it contains few magnets or because the restoring force is very great so that a given external field produces but a small displacement of the magnets. Thus the difference between the coefficients of magnetization of ferrous and ferric iron may be due either to the difference of the magnetic moments of the magnets in the atom in the two states or to a difference in the restoring force. If it is due to a difference in the magnetic moments the intensity of magnetization when the ferrous iron is saturated will not be the same as when the ferric iron is saturated, whereas if it is due entirely to the difference in the restoring force the saturation magnetization will be the same in the two cases. We can distinguish between these effects by Weiss' Theory of Magnetons as the number of magnetons is proportional to the magnetic moment. The result of the application of this theory is that the number of magnetons per atom of iron in ferrous sulphate is 27, in ferric it is 29. As the coefficient of magnetization differs more widely than these numbers, it follows that the restoring forces must be different in the ferrous and ferric salts. In the iron in potassium ferrocyanide Weiss finds that there are only ten magnetons. The difference between the number of magnetons in the trivalent and divalent condition is more pronounced in chromium and cobalt than it is for iron, thus for trivalent chromium the number of magnetons is 19, for divalent 25, in trivalent cobalt the number is 17, in divalent between 24 and 26; thus in both these metals the number of magnetons in the trivalent condition is less than in the divalent, whereas in iron the trivalent form is slightly richer in magnetons than the divalent. A very striking case of the variation of the number of magnetons with chemical composition is that of the oxides and sulphides of vanadium. Wedekind and Horst[27] give the following values for *k* the coefficient of magnetization and *n* the number of magnetons in various compounds of vanadium.

	$k \times 10^6$	n
VO	50.06	13.9
V_2O_3	13.88	10.92
VO_2	3.73	4.19
V_2O_5	0.86	2.99
VS	7.22	5.86
V_2S_3	8.95	10.00
V_2S_5	12.55	11.90
VOCl	27.16	13.18
VN	4.13	3.92

Thus the effect of oxygen is of the opposite character to that of sulphur, an increase in the oxygen content decreases, while an increase in sulphur content increases the number of magnetons.

Let us now proceed to see how the magnetic properties of the salts of the magnetic metals are consistent with the following assumptions:

1. That the paramagnetism of these substances arises from the atoms of the paramagnetic element. Fe. Cr. Mn. . .

2. That the magnetic properties of these atoms arise from a want of symmetry in the distribution of the electrons in the inner layers.

3. That the distribution of these electrons and therefore the symmetry of their arrangement can be affected by intense electric forces arising from atoms with their electrons in the neighborhood of the atom of the magnetic element, and that such forces may also affect the restoring force of the electrons in the atom, *i.e.*, the force with which the system of electrons resists any displacement from their position of equilibrium.

We shall take in the first place the very large diminution in magnetic properties which takes place when the atom of the magnetic element is a constituent of a complex salt such as $K_4(FeCN_6)$ ferrocyanide of potassium. We may point out that this diminution may take place when the magnetic element occurs in a complex with the positive charge and not merely when as in $K_4(FeCN_6)$; the iron is a member of the negatively electrified group. Thus Feytis[28] has shown that the following cobalt salts are diamagnetic—$[Co(NH_3)6]\,Cl_3$, $[Co(N4_3)5Cl]Cl_2$, $[Co(N4_3)4Cl_2]Cl$ and $[Co(NH_3)_5\ H_2O]Cl_3$; though in all of these the cobalt atom occurs in the positively electrified portion of the complex molecule.

What is the condition of the atom of the metal in a complex salt? Let us take potassium ferrocyanide as an example, for similar considerations will apply to all the complex salts. In potassium ferrocyanide the iron atom has lost two electrons and is surrounded by 6CN radicles, all of which are negatively electrified. Considerations of symmetry suggest that these negatively electrified radicles are at the corners of an octahedron and the iron atom at the center. The cyanogen radicles are, using Werner's notation, in the first zone with the atom of iron and are much more closely attached to it than are the atoms of potassium which are in the outer zone. Thus by the close proximity of the negatively

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[27] *Chem. Berick.*, 45, 263 (1911).

[28] *Comptes Rendus*, 152, 708 (1911).

charged cyanogens, the atom of iron is exposed to an intense and very symmetrical field of force, and this would (1) give rise to a very strong restoring force; this, if there were no change in the magnetic moments, would until saturation is approached reduce the magnetization. (2) From its symmetry this field tends to make the arrangement of the electrons inside the iron atom more symmetrical and thus reduces the magnetic moment. Both effects occur, the magnetization at ordinary temperature is reduced so much that it is not able to overcome the diamagnetism which iron, like all systems containing electrons, possesses; the number of magnetons is, according to Weiss, reduced to ten, which is only about one-third of the number in an atom of ferric iron. Let us now consider simple salts either in solution or which contain water of crystallization. Since these are electrolytes, the negative constituents of the molecule, such as Cl, SO_4, NO_3, will not be in the inner zone with the iron or other magnetic molecule, but in the outer zone. Thus these negative constituents will exert but little influence on the iron atom, and thus its state and magnetic properties will be but little affected by the change of SO_4 for Cl_2 and so on. The molecules in the zone nearest to the iron atoms are water molecules; these are probably arranged symmetrically around the iron atom and it is also probable that there are six molecules of water in the inner zone. We may picture the atom of iron as at the center of an octahedron with the water molecules at its corners. As far as the geometrical arrangements are concerned, they are very similar to those of the ferrocyanide with water molecules in place of negatively charged cyanogen radicles. As the water molecules are as a whole uncharged, while the cyanogen ones are negatively charged, we should have expected the field of force to be much stronger with the cyanogen atoms than with the water molecules, so that in the simple salt both the restoring force and the tendency to make the distribution of electrons symmetrical would be less than in the complex salt. Thus both the magnetization and the number of magnetons would be larger for the simple salt than for the complex one. In the salt where iron is trivalent, the iron atom will have lost three electrons; while in the divalent ones, it will only have lost two. Thus there is a difference in the number of electrons in the atoms; this might of itself be supposed to affect the magnetization. In addition to this, since the charge on the trivalent atom of iron is greater than that on the divalent, its attraction on the water molecules will be greater, these will be drawn closer into the atom and will be more favorably situated for influencing the arrangement of the electrons in the atom of iron.

In the case of the oxides the conditions are more complicated, we should expect as a general result that in these compounds the closer the connection between the iron and the atoms with which it was combined the lower would be the magnetization and that anything which tended to loosen these bonds would increase the magnetization. A loosening of these bonds would, however, increase the chemical activity of the iron by rendering it easier for it to enter into other combinations, thus we should expect to find correlation between chemical activity and magnetization, a connection which is brought to light very clearly by the experiments of Pascal. From this point of view we can understand a remarkable result obtained long ago by G. Wiedemann, *viz.*, that the magnetic qualities of Fe_2O_3 were increased by mixing with it Al_2O_3; the substances are isomorphous and may combine and form a compound in which the iron is not so firmly bound to other atoms as in Fe_2O_3.

(To be continued)

Studies in the Projection of Light

PART VII

PARABOLIC MIRROR AND DISK SOURCE OF LIGHT (*Cont'd*)

By Frank Benford

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In this discussion of the characteristics of searchlight beams for arcs and monoplane incandescent lamps, certain interesting relations between the beam formation and mirror deformation are pointed out. These features have found practical application as has also the shop test method for determining the focal position of the light source. Some test data on the measurement of beam widths are also given and it is shown that, with care in the testing, the measured width will come remarkably close to the computed value. The degree in which the beam formation can be controlled by moving the light source is discussed and curves are given by the help of which a complete analysis of any particular case can be carried out without going to the expense of an actual trial. A graphical method of determining the distribution of light is developed, and this method (like the one shown in Part IV) gives us information about those regions of the beam that have not been determined by the purely analytical methods previously employed. In the next article of the series, a variation of this method will be used to determine beam characteristics at relatively short range. It is in this particular case that analytical methods fail on account of their complexity and the relative simplicity of the graphical method makes it a useful working tool.—Editor.

Testing Distance for Width of Beam

At distances which are adequate for a proper analysis of a searchlight beam, the beam width is, within certain limits, independent of the position of the arc with respect to the focal point. The reason for this is the narrowness of the bundles of rays given off by the edge zones of the mirror. These rays must be swung through a considerable angle before they appear as edge rays and thus appreciably increase the diameter of the beam. It is therefore to be expected that measurements of beam diameter can be made with considerable accuracy even in the types of searchlights that have no mark or mechanism for locating the focal point.

As an indication of what may be expected from a 60-in. pure carbon arc searchlight without "focus finders" or other mechanical aids to correct focusing, reference may be made to the data points given in Fig. 59, where each point represents a reading of angular beam diameter at a radius of 2300 ft. plotted against the crater diameter measured after the carbons had cooled off. These data were collected during the development of a 200-amp. electrode, and some of the earlier samples had rather poor operating characteristics, which increased greatly the difficulty of the photometry and added to the uncertainty of estimating the real diameter of oblique and uneven craters. These factors undoubtedly increased the scattering of the points, but if an average is taken of all points this average will be found to agree to within a few minutes of arc with the computed width, which should fall on the straight line in the diagram. The good agreement here is not the result of highly accurate focusing, for in these tests the searchlight operator and trainer between them kept the arc in focus by observing the general formation of the beam, more particularly in the central parts. If the beam width at this distance had been easily influenced by the adjustment of the electrodes, the difference between observed and computed widths would probably be much greater.

The beam width, being almost wholly a function of the crater and mirror dimensions, and only in a slight degree dependent upon the focal adjustment, is an excellent datum point from which to compute the other beam characteristics. To obtain the testing distance for measuring the width of beam we can, therefore, most conveniently use the formula

$$L_e = \frac{114.6}{C \sin\frac{3a}{2} \cos^3\frac{a}{2}} F \text{ inches} \qquad (108)$$

where C is the observed width of beam in degrees, F is the focal length in inches, and a is the angle from the axis to the edge of the mirror. The observed beam width C at the range L_e has an excess E over the true beam width which may be computed by equation (107) or read from the curves of Fig. 60. There are certain test conditions under which the straight section between the mirror and true curved boundary may be encountered, and to guard against this happening it is often wise to determine the least safe testing distance in the same manner as was outlined for the spherical source. These safe distances are plotted in Fig. 61, and if used as a check on the curves of Fig. 60 they will insure the reality of the data of these latter curves.

The solid section of each curve of Fig. 61 may be used for arc searchlights, in which the mirror must necessarily be limited to a useful arc of 90 deg. from the axis. The dotted section is, therefore, useful only for monoplane incandescent lamps or similar light sources.

The minimum safe distance occurs for the ray from the edge of a mirror of 68 deg. angle from the axis. This does not differ much from the standard Army and Navy mirror, which varies between 60 deg. and 65 deg. depending upon size.

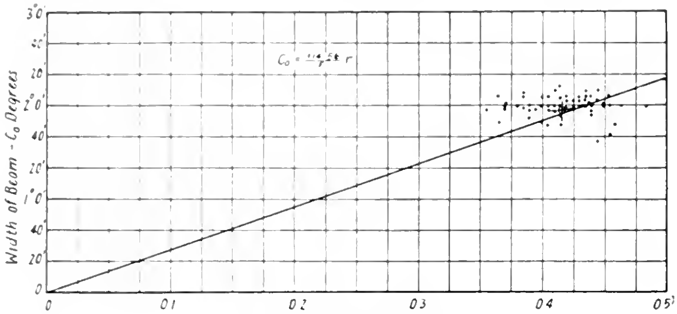

Fig. 59. The crater diameter of a plane carbon arc is constantly undergoing changes during the burning of the electrode and while a single comparison of measured and computed beam diameter may fail to be consistent, as illustrated by the distance of some of the points from the computed line, a number of determinations even under adverse conditions will give an accurate average

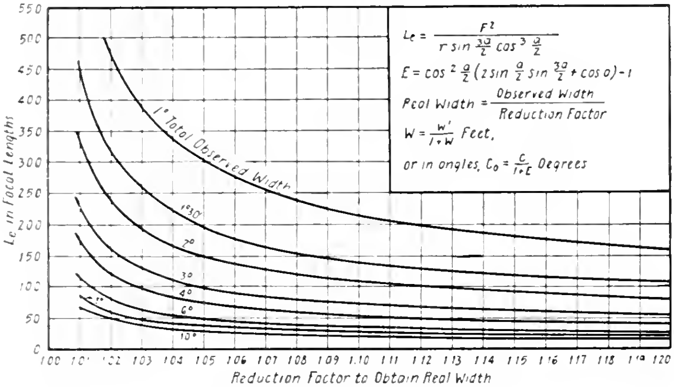

Fig. 60. When it is necessary to make a beam test at relatively short range the measured beam width will exceed the true width by the factors given in this diagram, which should always be consulted first to make sure that the test deals with the true curved edge of the beam

A question might properly be raised as to the validity of the solution given for edge rays when dealing with a disk source. The elemental images are (except for the one from the exact center of the mirror) elliptical in section with the small axis in the meridian plane in which all the computing has been done, and with the long axis at right angles to this plane. It may be thought that determining the *maximum* width of the beam from the *minimum* width of the elemental image is perhaps not a logical process, and the real maximum beam width might be determined by some section of the elemental beam that extends farther from its own axis.

No analytic proof is here offered for the correctness of the solution in the meridian plane, but in Fig. 62 a number of elemental beam sections are drawn accurately to scale to illustrate how they overlap, and how the greatest distance from the axis of the beam is reached by the end of the minor axis of some particular elemental beam. The particular case chosen is that of a disk source of a radius of one per cent of the focal length, and the section through the beam is taken at the beginning of the curved edge boundary as determined by equation (108) when the angle *a* has the value 45 deg.

The circle *A*, Fig. 62, is a section of the elemental image from the center of the mirror. Ellipse *B* is from the 30-deg. point on the mirror, and it is removed from the center of the beam by the radial distance of that point. Ellipse *C*, shown dotted, is from the 45-deg. point but it is overlapped very slightly by the elliptical beam from the 60-deg. point on the mirror. This overlap is due to the 60-deg. beam forming what has been called the initial straight edge, which has been shown previously to be slightly outside the nodal point of the curved edge. The circle *E* is drawn tangent to the outer end of the minor axis of the 60-deg. beam and it includes within it all of the elemental beams. The same would quite evidently be true if we had stopped at the 45-deg. or the 30-deg. point.

Determination of Focal Position by Measuring the Beam Width at Short Range

The exchange of rays between the center and edge of the beam leads to the submergence of the initial edge rays and at relatively short range they are well within the boundaries, but before this occurs there are two uses at least to which we may put these rays from the edge of the mirror. The manufacturing processes of producing parabolic mirrors has been reduced to a quantity basis, but still there are variations of focal length great enough to have a serious effect on the beam. Some kind of test for focal length is therefore required, and about the most accurate and convenient method makes use of these edge rays.

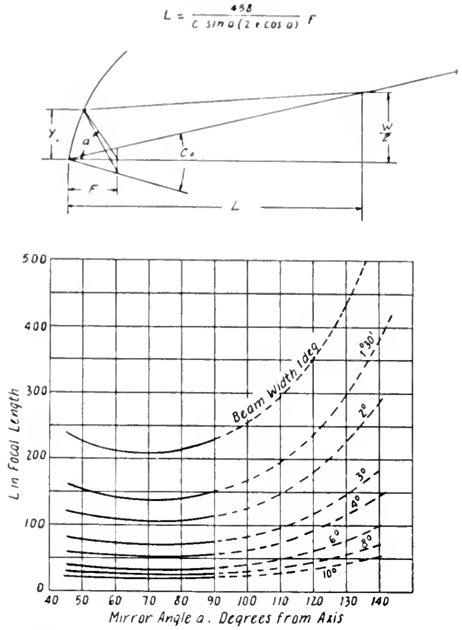

Fig. 61. When the mirror angle is greater than 45 deg., the edge ray intersects the curved edge o the beam at a relatively sharp angle and measurements of beam width at a range short of this point of intersection cannot be corrected by the data of Fig. 60. The curves of Fig. 61 may be used to make certain that only the curved edge of the beam is involved in the width measurement

As an example, let us take the case of a 60-in. mirror supposedly of 25 in. focal length but actually of 25.25 in. focal length. This is greater variation than is ordinarily found, but as will be demonstrated it indicates the order of accuracy of the test even when the original assumption of focal length is greatly in error. Also, in the following computations the value of F is used just as if it were known, but the error in the final results from using F, the erroneous value, is not large enough to be of importance.

From equation (103) the beginning of the curved part of the beam edge begins at 3140 in. for a 0.54-in. diameter crater and a focal length of 25 in. The curve of Fig. 60 also indicates that for this beam of 1 deg. 14 min. width some 125 focal lengths, or 3125 in. will be the distance of the beginning of the curved edge. Taking some distance considerably less than this, say 1200 in. so as to be certain of dealing only with the particular edge rays we want, the computed width of the beam W_e is from equation (55) and (104), using $a = 30$ deg.,

$$\frac{W_e}{2} = 34.05 \text{ inches.}$$

If a target having a circle of 34.05 in. radius drawn upon it is erected at 1200 in. from the searchlight and the beam is directed upon it, the beam radius when the arc is at the 25-in. position will be about 44.45 in. radius. When the arc is moved forward to bring the beam diameter down to the diameter of the circle, the relative rates of motion will be some 41.6 to one, that is, a movement of one inch along the axis gives a movement of 41.6 in. across the target. This ratio is not quite exact (F not being known exactly), but if the crater is advanced until the beam has the diameter of the circle, the focal point will be determined to within a few hundredths of an inch. The mirror angle instead of being 60 deg. as assumed is exactly 61 deg. 22 min., and if the value is used in connection with the true focal length of 25.25 in., the diameter of the circle should be 34.55 in. The difference between this value and the 34.05-in. circle is 0.50 in. and dividing by the ratio 41.6 the result 0.01 in. indicates the degree of approach to the true focal point. The error in the final determination is only one twenty-fifth of the original error made in assuming the focal length to be 25 in. The method is thus

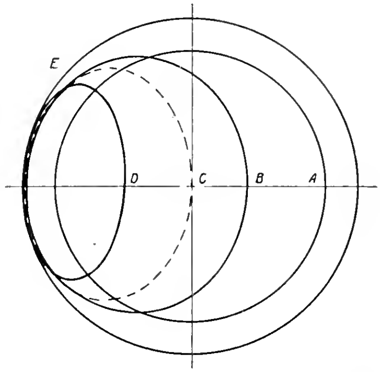

Fig. 62. The location of the 0, 35, 45, and 60-deg. elemental images within the beam limits of a 60-deg. mirror beam shows the end of the minor axis of the 60-deg. (ellipse D) image lies at the beam limits. For images from greater mirror angles, this will no longer be true

accurate enough for shop practice, and on account of its simplicity it is to be preferred to other more complicated methods such as mechanical measurements on the mirror or photometric explorations of the beam.

Truing the Mirror Ring by Observing the Beam Formation at Short Range

It sometimes happens that a searchlight mirror, mounted in a searchlight, becomes deformed due to stresses set up in shipping or by rough usage. This deformation is ordinarily not visible either in the mirror or in the beam, and while there is a great loss of central intensity the condition of the mirror may entirely escape attention. If the beam is directed normally against a wall at short range, say at 100 ft. as in the previous section, the beam outline will be observed to deviate from a circle. If now the normal diameter of beam for that range is computed and a circle is accordingly drawn on the wall, the extent of the deformation can be accurately determined and proper steps taken for its correction. The edges of the mirror may be forced forward or backward slightly at various points by adjusting the packing or applying force to the mirror ring, and it is a comparatively simple operation to make the beam a true circle. With the outer zone of the mirror in true alignment there is not much possibility of the more central parts having any deformation that was not there before mounting.

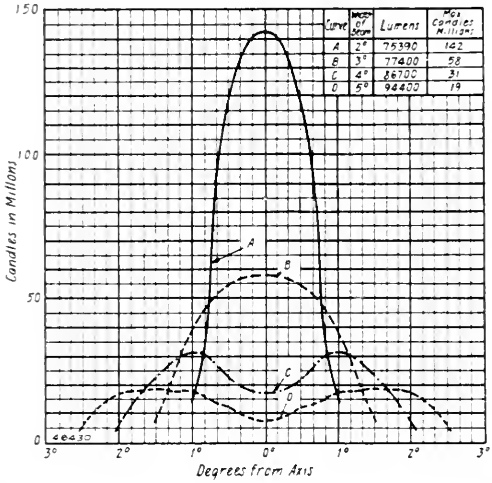

Fig. 63. The sensitiveness of the beam to focal adjustment is illustrated by the drop in central intensity when the beam is spread from 2 to 3 deg. in total width. At the same time there is a considerable increase in the light in the beam proper

Movement of Source

The practice of throwing the arc out of focus to widen the beam is not so common as it is in incandescent service, but there are occasions when a spread arc beam is useful. There is a considerable difference in the reactance of the beam to a movement of the arc, but if we consider the physical surroundings of the crater these differences are readily understood.

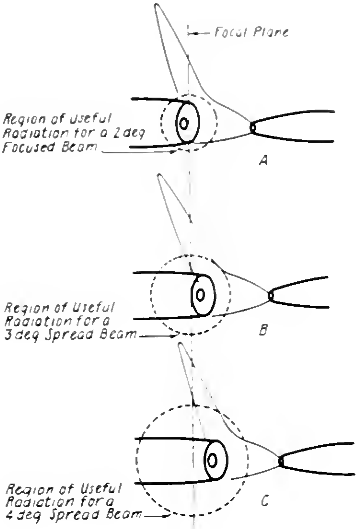

Fig. 64. The region surrounding the crater that contributes light to the beam is always a circle providing the crater is circular. This circle has a fixed diameter equal to the maximum diameter of the beam, and hence covers a greater region as the beam is expanded

The typical incandescent lamp used for projection purposes has a rather definite outline and, aside from the image formed by the bulb which may not exactly coincide with the filament, the intensity of the source is zero at points just outside of the filament. In the case of the arc there is no definite outline to the source, for while there is a very sharp and distinct drop in brilliancy at the edge of the crater, still the light radiated from the regions surrounding the crater may amount to a considerable part of the total radiation. To enumerate, there are the glowing outside walls of the positive electrode, the hot tip of the negative electrode, the violet arc stream between electrodes, and the flame above the crater, which often attains considerable size and brilliancy.

As the crater is moved away from the focal point the first result is a rather sudden decrease in central beam intensity as illustrated by curves *A* and *B* of Fig. 63. This decrease makes the point where the intensity falls to 10 per cent of the new maximum move outward from the axis, and the additional light so included raises the measured beam flux. Thus in the curves of Fig. 63 the sharply focused beam had 75,390 lumens against 94,400 lumens in the 5-deg. beam.

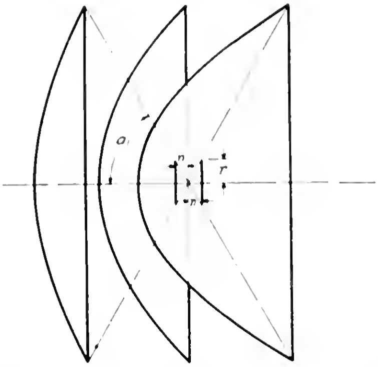

Fig. 65. This diagram illustrates how the light source may be moved either way along the axis without changing the central beam intensity providing the mirror does not extend to 90 deg. from the axis. If the mirror contains a 90-deg. zone, any movement away from the focal point will cause a loss of intensity in the center of the beam

The three sketches of Fig. 64 are intended to illustrate the manner in which the region surrounding the focal point contributes light to the beam. The beam diameter is really fixed, for a focused arc, by the light from the center of the mirror. Let us say that the crater subtends an arc of 2 deg. from this position, so that sketch *A* of Fig. 64 will correspond to curve *A* of Fig. 63. Measuring from a point near the rim of the mirror a 2-deg. circle will exceed the crater in size and will include a certain amount of light from the side of the electrode, and from the arc stream and the positive flame.

When the crater is thrown out of focus the circle surrounding the area of useful light expands in the same proportion as the beam boundaries and more light from the surrounding regions is included as will be seen from the sketches corresponding to curves *B* and *C*.

It is not necessary to advance the crater toward the mirror in order to secure this increase of flux, for practically the same results are obtained by drawing it back from the mirror. In this case the arc stream and the tip of the negative contribute more and the sides of the positive less.

Returning again to the idealized crater or disk source, Fig. 65, the distance through which it can be moved along the axis without decreasing the central beam intensity is

$$n = \pm r \cot a \qquad (109)$$

where a, the mirror angle, is never more than 90 deg. Where the mirror contains a 90-deg. zone, the disk must remain coincident with the focal plane regardless of any movement allowed by other zones.

In Fig. 66 the angle of spread e is given approximately by

$$\tan e = \frac{(S \sin a \mp r \cos a)}{p} = \frac{(S \sin a \mp r \cos a)\ (1+\cos a)}{2F} \qquad (110)$$

This spread is for any selected angle a, but there will be some particular angle or angles that will give a maximum spread.

Applying the method used to derive equation (62) for the spherical source, we have

$$L_e = \frac{dy}{d\ (\tan e)} = \frac{2\ F^2 \sec^2 \frac{a}{2}}{S\ (\cos a + \cos 2a) \pm r \sin a\ (1+2 \cos \mathrm{a})} \text{ inches} \qquad (111)$$

and as we are interested only in the limiting width when L_e is infinity, the denominator of (111) may be set equal to zero, giving the relations between the zone a that gives the maximum spread and S and r.

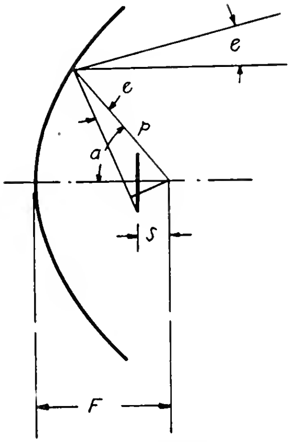

Fig. 66. The ray of maximum divergence originates on the edge of the crater that is farthest removed from the focal point, but the point on the mirror at which reflection takes place must be solved for as it varies with the relative size of the movements along the axis as compared with the radius *r* of the source

$$S = \pm r \sin a \frac{1+2\cos a}{\cos a + \cos 2a} \text{ inches} \qquad (112)$$

This equation does not contain the focal length as a direct factor and, therefore, the relative size of r to F does not change the zone at which the maximum divergence occurs. This is not the exact fact of the case, but is a result of the simplified expression used for the angle e. The results are sufficiently close for practical use, as it has been found in the case of the spherical source that a relatively wide mirror zone gives the same angle of spread as closely as can be measured, and an accurate determination of angle a is not necessary.

Equation (112) is plotted in Fig. 67 which must be used with the foregoing limitation in mind; that is, the source must not be large, say not over 0.1 F, and the movement S must not be over 0.3 F. These limits are well beyond ordinary practice.

The curves of Fig. 67 may be used in connection with equation (110) to compute the maximum spread of a searchlight when the lamp is moved to the limit of its travel. The following question was recently asked: How wide is the beam from a 24-in. mirror of 15 in. focal length when the lamp is moved 2.5 in. toward the mirror, or 1.5 in. away from the mirror? The radius of the crater is 0.27 in.

We are dealing with an arc and it is obviously only angles on the mirror of less than 90 deg. that have any significance. For the position toward the mirror the ratio of S to r is 9.26. The curve in the lower left corner of Fig. 67, when produced, indicates a mirror angle of some 55 deg. This particular mirror extends only to 43 deg., so the maximum spread will be found in the rays reflected from the extreme edge of the mirror.

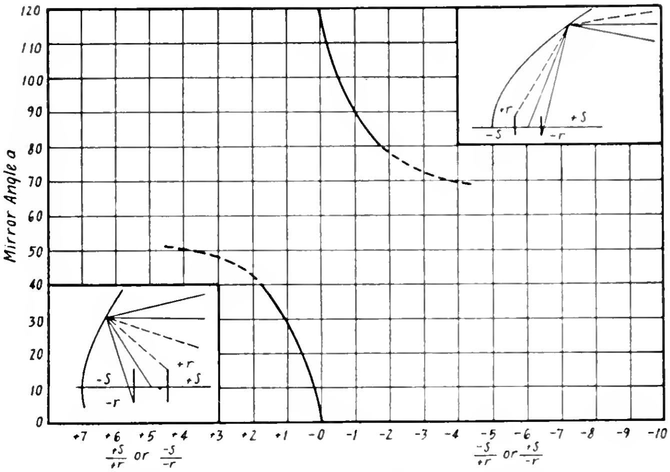

Fig. 67. There are two mirror zones, one below 60 deg. and the other above 60 deg., that give the ray of maximum divergence when the disk source is displaced from the focal position

Substituting numerical values in equation (110), the half width is found to be 6 deg. 30 min. or a total width of 13 deg. for the position toward the mirror and 8 deg. total width for the position away from the mirror. Without the use of Fig. 67 it would be necessary to explore the mirror, either graphically or analytically, or perhaps run a test in order to arrive at the angle of maximum spread.

First Graphical Method of Obtaining the Beam Characteristics

Circular Elemental Images

The graphical determination of the arc beam depends on a simplification of the elemental images in order to arrive at a working method. This simplification does not adversely influence the ultimate accuracy of the results and it does make it possible to reduce a difficult problem to simple terms. This particular method has been used by the author for eight years and has yielded excellent results in the building up of the searchlight beam from the brilliancy data of the crater. The synthetic beams so computed have been an excellent check on the beam tests and where disagreements have appeared there has always been found some physical explanation in either the searchlight or the test. As will be explained more in detail later this circular elemental image gives its best results for mirrors of less than 90 deg. angle. Deeper mirrors require that attention be given to some of the details that are omitted in developing the circular image.

From the center of the mirror the crater appears circular and the projected elemental beam is also circular and of the same angular width as the crater. From a point in the 60-deg. zone of the mirror, the crater appears to be elliptical in form with a minor axis half the length of the major axis. The projected beam has the same proportions and is also reduced in all dimensions inversely as the length of the line from mirror to focal point. The solid angle subtended by the crater as viewed from the 60-deg. point is only 0.28 of the solid angle from the center, and the projected beam suffers the same reduction in size.

If the light is reflected from a small section of mirror in the 60-deg. zone directly above or below the arc, the projected elliptical beam will have its major axis horizontal; a mirror section on either side of the mirror will give a beam with a vertical major axis; and intermediate mirror points will give intermediate directions to this axis. At sufficient distances these elliptical sectioned beams will overlap as in Fig. 68 where six such beams are superimposed. The central area which is covered by all six beams is a circle having a diameter equal to the minor axis, and going outward on a radial line the number of beams on successive points will be found to be 5, 4, 3, 2, and 1, reaching zero at the outer circle of radius equal to the major axis.

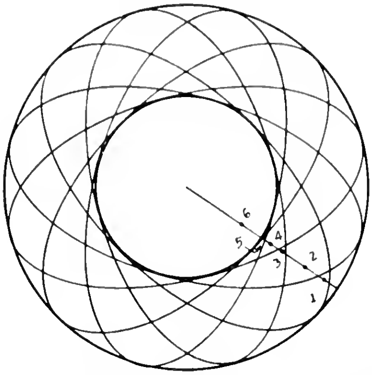

Fig. 68. Diagram showing how the elliptical shaped elemental beams from the edge of the mirror overlap, giving a central circular region of full intensity

The difficulty of exactly summing an infinite number of such ellipses corresponding to the infinite number of points around the circumference of a mirror zone is fairly obvious, but ordinarily there is small need for such a solution for we may represent any single ellipse by a circle of equal area, as in Fig. 69, and the infinite number of circular beams will immediately add to a single beam of equal diameter and the proper intensity. The summation of the circular beams from the various mirror zones can then be carried out in a manner similar to the method employed for the spherical light source. The only difference between the two sources is that the elemental beam diameter of the disk source is reduced by the square root of the cosine of the mirror angle a; and in terms of the focal length F and the radius r of the source, the elemental beam width is

$$C_{ave.} = \frac{57.28\, r}{F}(1+\cos a)\sqrt{\cos a} \qquad (113)$$

The intensity of the beam is determined by the brightness B of the source, the coefficient k of the mirror, and the projected area of the zone, as given by equation (79).

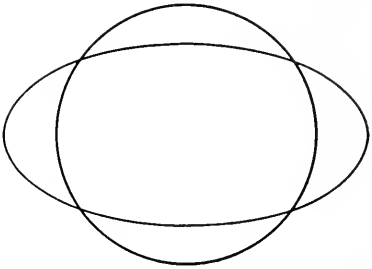

Fig. 69. Diagram showing how the ellipses are reduced to equivalent circles for making the graphical solution for the beam

The summation of zone images is illustrated in Fig. 70, where the rectangular areas represent zonal beams, the dimensions of which are given in Table IV. The narrower zonal

TABLE IV

ZONE AREAS AND IMAGE WIDTHS

Unity Focal Length and Disk Light Source of Radius $r = \frac{F}{100}$

ZONE BOUNDARIES		Mid Zone a	PROJECTED AREA		Radius p	$\sqrt{\cos a}$	IMAGE RADIUS	
From	To			Total			Degrees	Per Cent
0°	10°	6° 40′	0.096	0.096	1.004	0.996	0° 34.1′	99.0
10°	20°	15°	0.295	0.391	1.018	0.983	0° 33.2′	96.7
20°	30°	25°	0.512	0.903	1.049	0.952	0° 31.2′	90.7
30°	40°	35°	0.762	1.665	1.100	0.905	0° 28.3′	82.3
40°	50°	45°	1.064	2.729	1.172	0.841	0° 24.7′	71.8
50°	60°	55°	1.455	4.184	1.271	0.757	0° 20.5′	59.6
60°	70°	65°	1.972	6.156	1.405	0.650	0° 15.9′	46.3
70°	80°	75°	2.697	8.853	1.588	0.509	0° 11.0′	32.0
80°	90°	85°	3.713	12.566	1.839	0.295	0° 5.5′	16.0
90°	100°	95°	5.290	17.856	2.189	0.295	0° 4.6′	13.5
100°	110°	105°	7.794	25.650	2.699	0.509	0° 6.5′	18.8
110°	120°	115°	12.045	37.695	3.461	0.650	0° 6.5′	18.8

beams come from around the 90-deg. position on the mirror and the beams from higher angles are wider. The two upper zonal beams in the illustration are seen to overlap the beams from the 80- to 90- and 90- to 100-deg. zones. In making the graphical summation the overlapping parts are brought down to make contact with the rectangles below. When this has been done the images pile up as on the right of Fig. 70, and the characteristic curve can now be drawn through the middle of the steps formed by the rectangles.

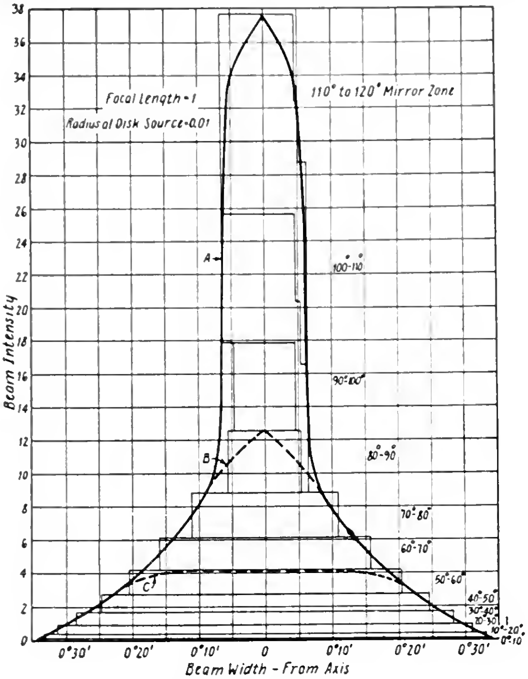

Fig. 70. The zonal images from a disk source are widest for the 0-deg. zone and for a zone slightly above 90 deg. The 90-deg. zone gives a minimum width and a second minimum may occur if the mirror angle extends to beyond 120 deg. To the left of the center line the rectangles representing the intensities and widths of the zonal images are piled on top of one another so that some of the upper ones overhang smaller ones below. On the right, the overhanging parts are slipped down to make contact with the rectangles below

The peak of the curve is known to be a point when the mirror contains a 90-deg. zone as it has already been pointed out that such a mirror does not have an inverse-square region or a crest on the beam. If the mirror stops short of 90 deg. the width of crest can be found by the equations developed when discussing the inverse-square region of the disk source beam.

The dotted curves give the beam characteristics of the same mirror (F constant) reduced to 90 deg. and 60 deg.

In Fig. 71 are drawn the beams from three mirrors of equal diameter and variable focal length and having disk sources of 0.01 the focal length of the 120-deg. mirror. These characteristic curves were derived directly from Fig. 70 by increasing the peak intensities to a common value as called for by the common projected area of the three mirrors and reducing the widths inversely as the focal lengths.

The general relations here exhibited are the same as found for the spherical source, but the differences between the three are somewhat increased. The wide angle mirror gives a wide beam, but the distribution of light is such that its usefulness is rather limited. It might be used, for example, for lighting a group of statuary in which the central figure is to be brought out with especial prominence, but for searching or illuminating difficult targets the wide zone of low intensity around the edges makes it distinctly inferior to the clean-cut beam from the narrow angle mirror. It is for this reason that so many incandescent lamps of the monoplane type have shallow mirrors rather than deep ones, and it is only in the case where volume of light is more important than uniformity that the deep mirror is to be desired.

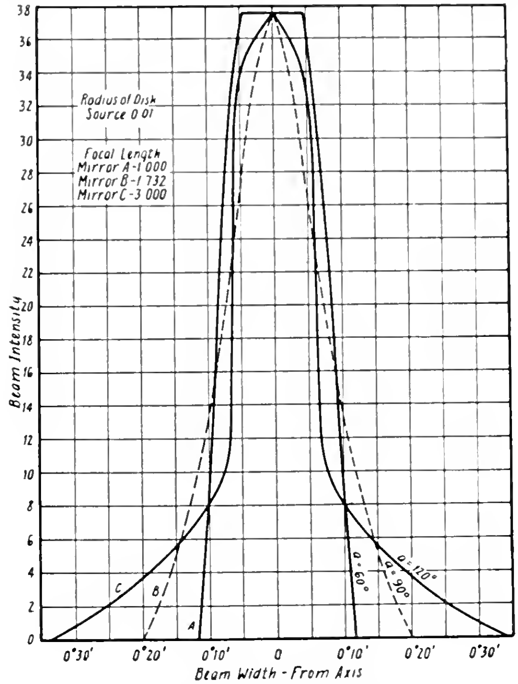

Fig. 71. Three mirrors of equal diameter but different focal length give equal central intensities but different beam widths. The sharp point to two of the characteristic curves indicates the presence of the 90-deg. zone in the mirror.

(To be continued)

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alternators

Waterwheel Generators and Synchronous Condensers for Long Transmission Lines. Smith, M. W.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 894-903.
(Illustrated paper on design and operation of such machinery.)

Ball Bearings

Approach of Flat Elastic Plates Under Load when Separated by a Ball of Similar Material. Goodman, John.
Engng., Aug. 24, 1923; v. 116, pp. 244-246.
(Results of tests to determine the load-carrying capacity of balls.)

Brakes, Dynamic

Compound Characteristics in Regenerative Braking with Direct-current Traction. Say, M. G. and Frampton, H. G.
I.E.E. Jour., Aug., 1923; v. 61, pp. 863-868.
("Deals with a particular form of regenerative braking for d-c. trains, effected by application of a differential compound field excitation to the traction motors.")

Condensers, Steam

Testing Jet Condensers. Long, L.
Power, Aug. 21, 1923; v. 58, pp. 293-296.

Eddy Currents

Eddy Currents in Iron Masses. Rosenberg, E.
Elec'n, Aug. 24, 1923; v. 91, pp. 188-191.
(On the theory of eddy currents.)

Electric Control Systems

System of Coal and Ore Bridge Traverse Control for Protection Against Wind and Skewage Hazards of Skew Type Direct-current Bridges. Canney, P. R.
Assoc. Ir. & St. Elec. Engrs., Sept., 1923; v. 5, pp. 425-447.

Electric Drive—Foundries

Complete Electrification of the Foundry Industry. Egan, Leonard W.
Assoc. Ir. & St. Elec. Engrs., Sept., 1923; v. 5, pp. 381-424.
(Considers drive of various kinds of foundry machinery, electric welding, electric melting furnaces and core ovens, electric cranes, etc.)

Electric Drive—Hoisting and Conveying

Single Bucket Blast Furnace Skip Hoist Characteristics. Cummins, A. C. and Leavitt, A. R.
Assoc. Ir. & St. Elec. Engrs., Sept., 1923; v. 5, pp. 449-466.
(Discusses the following types of equipment: single-motor d.c., double-motor d.c., single-motor a.c., Ward-Leonard a.c. or d.c.)

Electric Drive—Power Plant Auxiliaries

Drive of Power Station Auxiliaries. Breach, L. and Midgley, H.
I.E.E. Jour., Aug., 1923; v. 61, pp. 829-862.
(Deals with seven alternative schemes for supply of power to auxiliaries.)

Electric Drive—Pumps

Motor Operated Centrifugal Pumps in Steel Plants. Cornwell, B. A.
Assoc. Ir. & St. Elec. Engrs., Sept., 1923; v. 5, pp. 309-326.
(Selection of equipment, operating costs, etc.)

Electric Drive—Steel Mills

Adjustable-speed Motors for Driving Non-reversing Rolling-mill Trains. Bauer, Hellmut. (In German.)
Elek. Zeit., Aug. 9, 1923; v. 44, pp. 753-757.
(Pays special attention to three-phase induction motors.)

Reversing Mill Drive at Messrs. Cammell Laird & Co.'s Penistone Works.
English Elec. Jour., July, 1923; v. 2, pp. 256-264.

Electric Furnaces

Capacities of Electric Melting Furnaces. Brooke, Frank W.
Fuels & Fur., Sept., 1923; v. 1, pp. 355-357.
(Short article on selection of correct furnace.)

Electric Furnace Phenomena. Moore, Edward T.
Assoc. Ir. & St. Elec. Engrs., Sept., 1923; v. 5, pp. 529-582.
(Results of extensive tests.)

Electric Lamps, Gas Tube

Some Experiments Illustrating the Electrical Properties of Neon Lamps. Coursey, Philip R.
Wireless Wld. & Radio Rev., Aug. 22, 1923; v. 12, pp. 700-704.

Electric Lamps, Incandescent

Art of Sealing Base Metals Through Glass. Houskeeper, William G.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 954-960.
(Describes different methods of making successful seals between glass and base metals.)

Electric Meters

Wave Meter as a Substitute for the Oscillograph. (In German.)
Elek. Zeit., Aug. 9, 1923; v. 44, pp. 757-758.

Electric Motors—Starting Devices

Method of Starting Two-phase Motors. Hill, Norman B.
Elec'n, Aug. 31, 1923; v. 91, pp. 212-213.

Electric Testing

Relative Air Density in High-voltage Testing. Doyle, E. D.
Elec. Wld., Aug. 18, 1923; v. 82, pp. 329-330.

Electric Transmission Lines

110-kv. Transmission Line for Oak Grove Development of Portland Railway, Light & Power Co. Wakeman, H. R. and Lines, W. H.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 891-893.
(Short paper dealing with design methods.)

Electric Transmission Lines—Towers

Insulation Design of Anchors and Tower Supports for 110,000-volt, 4427-ft. Span Over Carquinez Straits. Corbett, L. J.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 887-890.
(Illustrated description of construction used for a line at San Francisco Bay.)

Electric Welding

Application of Electric Welding to Large Tank Construction. Rigby, E. J.
Am. Weld. Soc. Jour., Aug., 1923; v. 2, pp. 14-24.

Electrical Engineering

Systematizing the Work of an Electrical Engineering Division. Vanderwaart, P. T.
Assoc. Ir. & St. Elec. Engrs., Sept., 1923; v. 5, pp. 513-527.
(Methods of organizing the work in an electrical department of an industrial concern.)

Electrometallurgy

Making Iron from Ore by a New Electrolytic Process. Kreutzberg, E. C.
Iron Tr., Aug. 30, 1923; v. 73, pp. 595-598.
(Description of the plant and processes of the Milford Electrolytic Iron Co., Milford, Conn.)

Frequency Changers

Aligning a Frequency Changer Set.
Power, Aug. 21, 1923; v. 58, pp. 298-299.

Grounding

Present Day Practices in Grounding of Transmission Systems.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 928-946.
(First report of the Sub-committee on Grounding of Systems of the Protective Devices Committee of the A.I.E.E.)

High Frequency

Design of Inductances for High-frequency Circuits. Fortescue, C. L.
I.E.E. Jour., Aug., 1923; v. 61, pp. 933-943.

Inspection of Material

Inspecting by Magnetic Method. De Forest, A. V.
Iron Tr., Aug. 23, 1923; v. 73, pp. 531-533, 540.
(Methods of testing iron and steel for physical and mechanical properties.)

Insulating Oils

Purifying Transformer Oils.
Elec. Wld., Aug. 18, 1923; v. 82, pp. 338-339.
(Experiences of several companies.)

Insulation

How to Get Uniformly Good Results with Insulating Varnishes. Stringham, A. W.
Elec. Rec., Sept., 1923; v. 34, pp. 151-155.

Measuring Instruments

High Speed Stroboscope.
Engng., Aug. 31, 1923; v. 116, pp. 255-256.
(Description of a device for apparently reducing the speed of moving machinery so that its performance may be made visible.)

New Developments in Electric Telemeters. Peters, O. S. and Johnston, R. S.
Engng., Aug. 24, 1923; v. 116, pp. 253-254.
(Describes an instrument for remote reading and remote recording of pressures, stresses, strains, etc.)

Some Instrument Practices of the United Electric Light & Power Co. Caldwell, W. E.
Power, Aug. 21, 1923; v. 58, pp. 280-283.
(Methods and apparatus used in boiler plant testing.)

Mechanical Testing

Tests of Line Materials. Seelye, Howard P.
Elec. Wld., Aug. 26, 1923; v. 82, pp. 379-382.
(Pertains to tests of wooden pole line materials.)

Power Plants, Electric

Paradox of Hydro-steam. An Analysis to Show that Energy Generated by Combined Steam and Hydro Prime Movers Can Cost Less Than Either One Separately. Moore, George Holmes.
Engng. News-Rec., Aug. 30, 1923; v. 91, pp. 354-356.

Power-factor

Power-factor Correction with Loaded Synchronous Motors. Bates, Clifford W.
Elec. Wld., Aug. 18, 1923; v. 82, pp. 323-325.

Protective Apparatus

Operating Performance of a Petersen Earth Coil. Oliver, J. M.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 904-914.
(A report of the Alabama Power Co.'s operating experiences.)

Radio Engineering

Electrical Loud Speakers. Nyman, A.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 921-927.
(Treats of design and performance.)

Radio Receivers

Distortion in Valve Receiving Circuits. Pearson, S. O.
Wireless Wld. & Radio Rev., Aug. 29, 1923; v. 12, pp. 721-724.
(The first of a series of articles on distortion. This installment treats of distortion in high frequency circuits.)

Reactors

Operating Experience with Current-limiting Reactors. Pollard, N. L.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 915-920.
(Describes the troubles experienced with different types by the Public Service Electric Co.)

Repair Shops, Electrical

N. & W. Electric Shop Practices.
Elec. Rwy. Jour., Aug. 18, 1923; v. 62, pp. 257-260.
(Methods used in repairing electric locomotives.)

Rheostats

Liquid Slip Regulator or Rheostat. Petty, D. M.
Assoc. Ir. & St. Elec. Engrs., Sept., 1923; v 5, pp. 467-476.

Ship Propulsion, Electric

Electric Propulsion of Ships. Rothera, L.
English Elec. Jour., July, 1923; v. 2, pp. 245-255.
(Compares Diesel-electric with direct Diesel, and turbo-electric with turbine drive having reduction gearing.)

Electric Ship Propulsion. Metten, J. F.
Pacific Mar. Rev., Sept., 1923; v. 20, pp. 438-440.
("An analysis of the steam-electric drive from the standpoint of fuel economy.")

Skin Effect

Proximity Effect in Wires and Thin Tubes. Dwight, H. B.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 961-970.
(Mathematical. Includes bibliography of 18 entries.)

Statistics—Electric Cars

Economic Fields of Trolley Car and Bus. Topping, Victor.
Elec. Rwy. Jour., Aug. 25, 1923; v. 62, pp. 289-291.
(Tabulated statistics on costs of operation of double-truck and safety trolley cars, trolley buses and auto buses.)

Steam Accumulators

Steam Accumulator and Its Applications.
Power, Aug. 28, 1923; v. 58, pp. 322-326.

Street Lighting

New Practices in Street Lighting. Bettis, A. E.
A.I.E.E. Jour., Sept., 1923; v. 42, pp. 985-987.
(Describes an installation in Kansas City, Mo.)

Wire

Characteristics of Enameled Magnet Wire. Peaslee, W. D.
Elec. Wld., Aug. 25, 1923; v. 82, pp. 377-379.
(Desirable properties, test methods, etc.)

NEW BOOKS

Absolute Measurements in Electricity and Magnetism. Ed. 2. Gray, Andrew. 837 pp., 1923, N. Y., Macmillan & Co.

Drahtlose Telegraphie und Telephonie. Ed. 2. Lertes, P. 200 pp., 1923, Leipzig, Theodor Steinkopff.

Electric Furnace for Iron and Steel. Stansfield, Alfred. 453 pp., 1923, N. Y., McGraw-Hill Book Co., Inc.

Electrical Handling of Materials. Vol. 4: Machinery and Methods. Broughton, H. H. 334 pp., 1923, Lond., Ernest Benn, Ltd.

Elements of Machine Design. Ed. 2. Kimball, Dexter S. and Barr, John H. 446 pp., 1923, N. Y., John Wiley & Sons, Inc.

Hydraulics for Engineers and Engineering Students. Ed. 4. Lea, F. C. 594 pp., 1923, N. Y., Longmans, Green & Co.

Kent's Mechanical Engineers' Handbook. Ed. 10. 2247 pp., 1923, N. Y., John Wiley & Sons, Inc.

Power Plant Machinery. Vol. 1: Mechanism of Steam Engines. Ed. 2. James, Walter H. and Dole, Myron W. 277 pp., 1923, N. Y., John Wiley & Sons, Inc.

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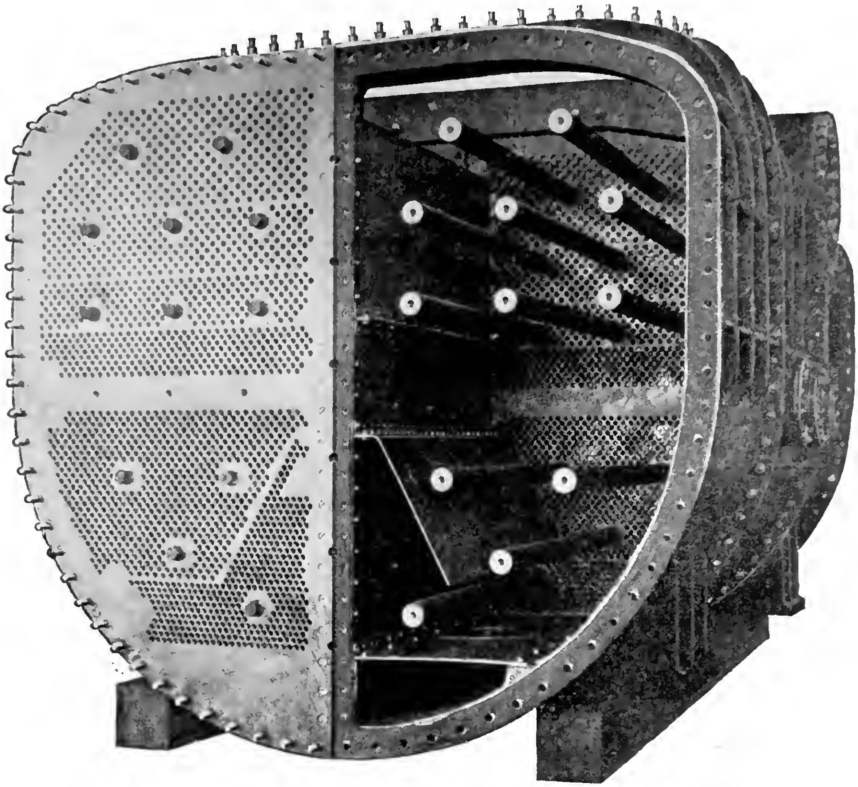

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5. The water circulation with two pumps lends itself to the highest operating economy. The circulating pump power is used to the greatest benefit by having one pump furnish water to the top tubes and the other to the lower tubes. At light loads or with cold water the lower supply (from "B" pumps) is shut off or reduced. This can be done without reducing vacuum. Practical operation consists of running the "A" pump for the top tubes at fixed speed while the "B" pump is varied to meet conditions.

6. The air devaporization and cooling is done in external coolers with intermeshed grid surfacers. It is being rapidly recognized that air devaporization is a distinctly different process from condensation and should be carried out in a separate apparatus, particularly designed for this work.

7. The air is cooled to low temperature and removed by a stem jet pump, a reciprocating pump, or a combination of the two. Many plants use the combination of Steam Jet Primaries and Motor-driven Secondary Reciprocating Dry Vacuum Pump. With modern turbines the feed heating should be done by steam bled from the turbine in preference to any other source, and this makes the motor-driven vacuum pump a more economical arrangement than secondary steam jets.

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EVERY careful buyer of copper wire studiously considers shipping facilities and freight rates as well as price and quality, before placing an important order.

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(C)—Freight rates and quickness of dispatch by sea or land (or both) are resultantly lower and quicker.

Cost of delivery and promptness of delivery, as affected by these facts, so often represent real purchasing economy, that they deserve equal consideration with price, quality and plant facilities on important orders for copper equipment.

We urge recognition of this fact upon all purchasers of copper wire.

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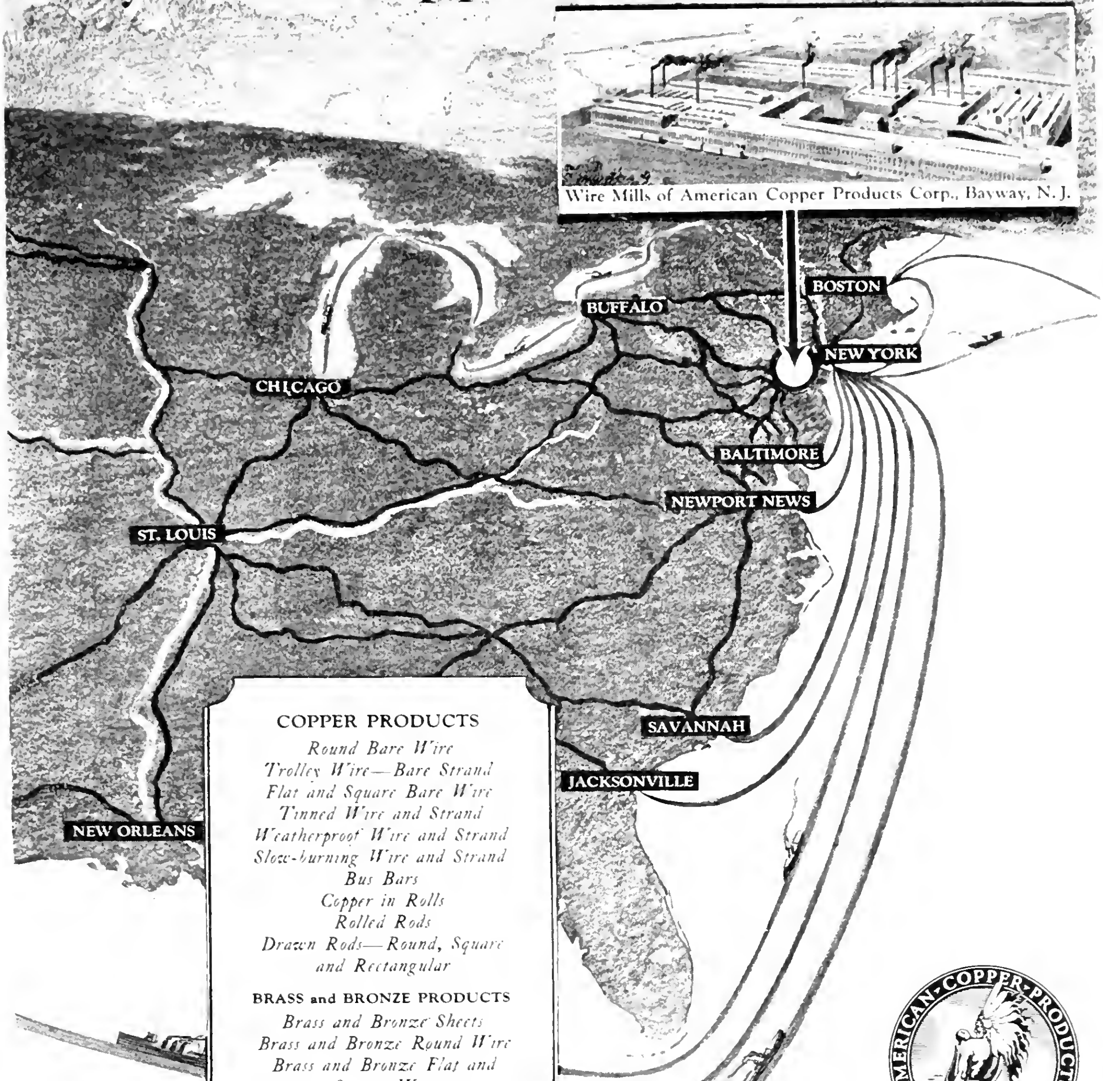

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OVER two miles of Electrode wire used per reel on these General Electric automatic and semi-automatic welders without **any** interruption of the arc.

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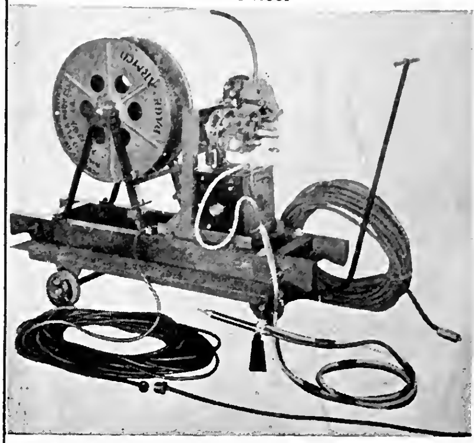
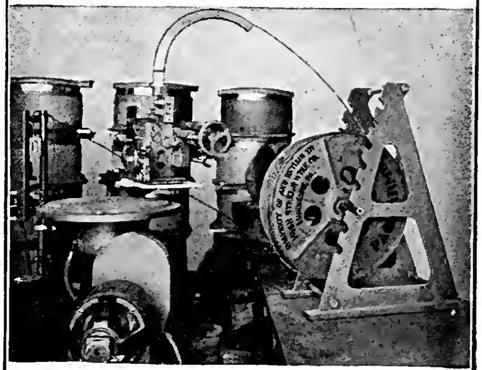
Blue tag denotes Electrodes. Ends of rods colored blue.

Yellow tag denotes Gas Welding Rods. Ends of rods colored yellow.



General Electric Semi-Automatic Arc Welder with Reel of Page-Armco Electrode Wire



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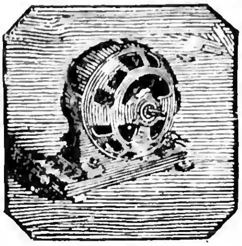

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SPACE limitation makes it very difficult to design plain-bearing housings so as to give ample protection against the entrance of foreign matter into the bearings of electric motors used in dusty and gritty locations or in places where they are exposed to the possible splashing of water.

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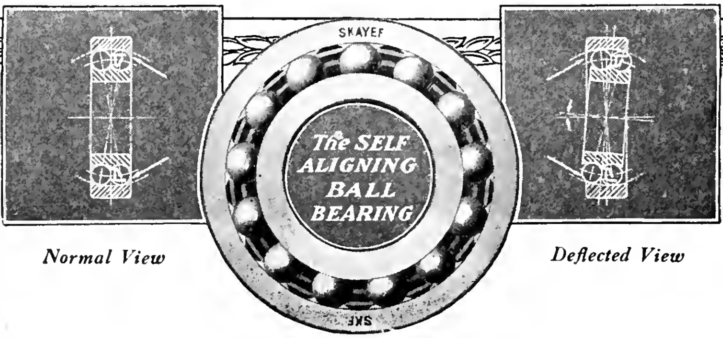

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The Wm. Cramp & Sons Ship & Engine Building Co.
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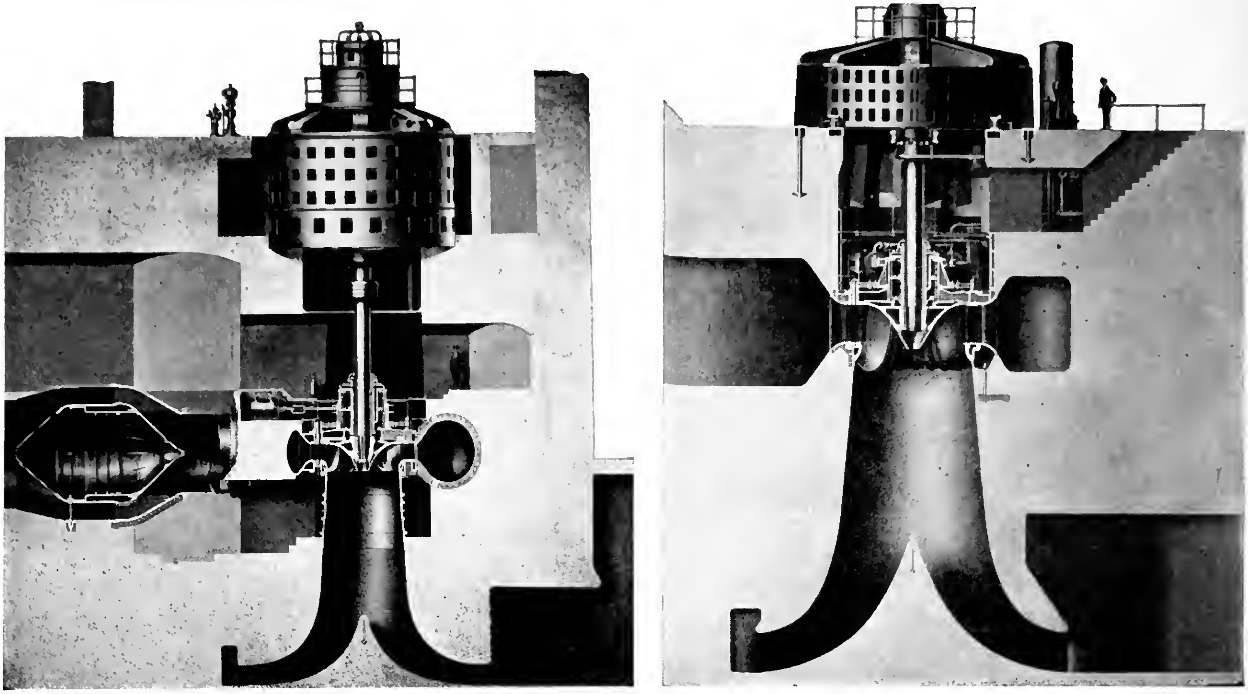

Some of the Contracts for I. P. MORRIS HYDRAULIC TURBINES awarded since January 1,1922

MANUFACTURED IN PHILADELPHIA

	No. of Units	Horse Power Per Unit	Head In Feet
Phoenix Utility Company (Powerdale Development)	1	8700	180
Niagara Falls Power Company (Plant 3-C)	2	70000	213.5
International Paper Company (Sherman Island Development)	1	10000	66
Adirondack Power & Light Corp. (Spier Falls Development)	1	9000	80
General Construction Corp. (Pinev Creek Development)	2	11000	75
Great Northern Paper Company (Anson Plant)	4	1500	20
Western New York Utilities Co.	1	3160	79
Washington Water Power Co. (Long Lake Station)	1	22500	168
Pennsylvania Water & Power Co. (Holtwood Plant)	2	20000	62
Amoskeag Manufacturing Co.	1	7500	45
Moreau Manufacturing Corp.	5	1500	15.5
St. Croix Paper Co.	1	4550	48
Kentucky Hydro Electric Co.	3	9850	220

MANUFACTURED IN MONTREAL

	No. of Units	Horse Power Per Unit	Head In Feet
Manitoba Power Company (Winnipeg River Development)	2	28000	56
Lower Sturgeon Power Company	2	4000	42
Maine & New Brunswick Elec. Power Co.	2	2000	85
Dryden Paper Company, Limited	1	1400	29
Spruce Falls Company, Limited	1	2500	25
East Kootenay Power Company	2	7500	190
Northern Ontario Light & Power Co. (Metabitchouan Plant)	4	3300	305
Montreal Light, Heat & Power Cons. (Cedars Plant)	4	11300	30
Montreal Light, Heat & Power Cons. (Cedars Plant)	2	1500	30
Price Bros. & Company, Limited	1	11000	72
Howard Smith Paper Mills, Limited	2	350	8
Hydro-Electric Power Commission of Ontario (Queenston Chippewa Development)	3	58000	294
St. Maurice Power Company	4	30000	60
Rolland Paper Co. Ltd.	1	750	20
Northern Canada Power Co.	2	10000	70
Hollinger Gold Mines, Ltd.	2	12000	60
Southern Canada Power Co.	6	5600	50

842,810 Horse Power to be Delivered by I. P. Morris Turbines Contracted for Since January 1, 1922

I. P. Morris Hydraulic Turbines Installed and under Contract have a total Capacity of 3,517,040 Horse Power

Designers and Builders of the Johnson Hydraulic Valve

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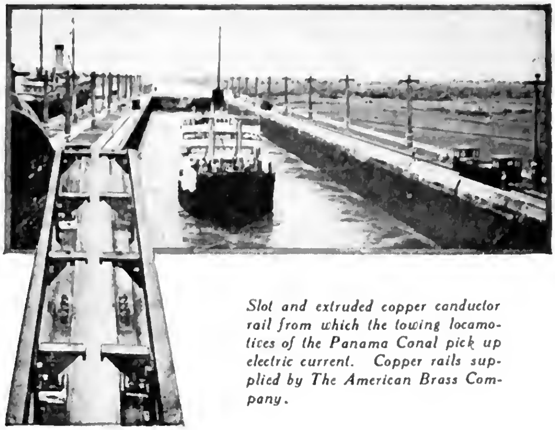

Slot and extruded copper conductor rail from which the towing locomotives of the Panama Canal pick up electric current. Copper rails supplied by The American Brass Company.

PANAMA CANAL
Specifications Plus

WHEN the specifications for the T-rails which feed electric energy to the Panama towing locomotives were drawn by the Isthmian Canal Commission a conductivity of 96% was demanded.

The contract was awarded to The American Brass Company. The rails were produced by the extrusion process and when treated by the Bureau of Standards had a conductivity of 99.6% at 20° C. in terms of the International Annealed Copper Standard—nearly 4% more than the government required.

Frequent tests made during the course of manufacture showed that the government standard was consistently exceeded and that the purity of the Anaconda Copper used was 99.9%.

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ANACONDA AMERICAN BRASS LIMITED
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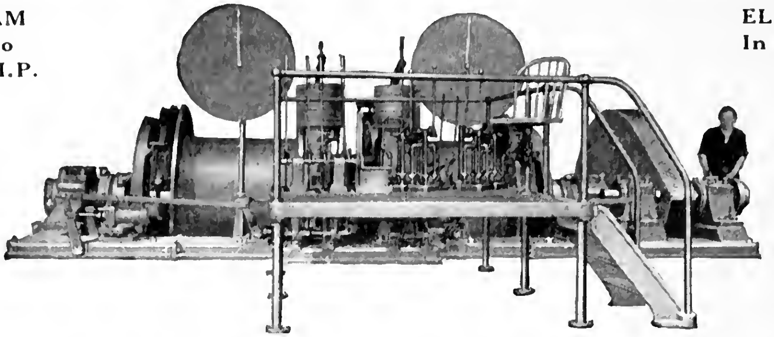

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Your own evaporator plant can produce distilled water for storage batteries.

Capacity 30 gallons of distilled water per hour with steam supplied at 60 lbs. gauge.

This set consists of evaporator, condenser, aerating filter, and interconnecting piping, all mounted on an angle-iron frame for attaching to wall.

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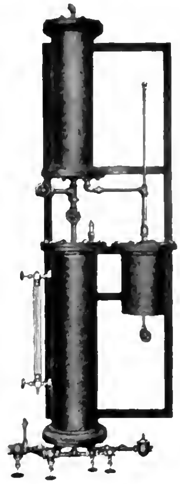

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NEW DEPARTURE BALL BEARINGS AND THEIR UNIVERSAL APPLICATION
ENGINEERING INFORMATION
2 H.P. 200-Cycle Induction Motor

JUST now the makers of all devices incorporating electric motors or generators are showing new interest in the peculiar advantages of ball bearings for increasing both the efficiency and salability of their product.

To assist those who wish to look into the subject we have compiled in a special binder engineering data bulletins showing application in 41 types of machines, together with general mounting directions, load charts and dimensional data. This material will be furnished free upon request. Ask for the "special bulletins on electrical machinery."

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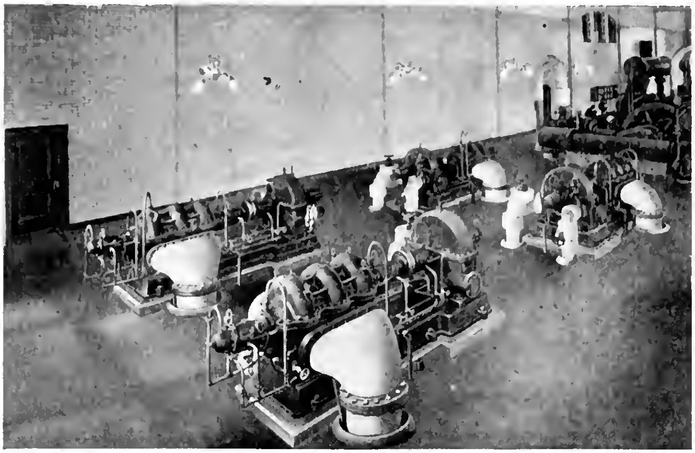

The combined pump and turbine units illustrated combine maximum sustained efficiency in continuous hard service with reliability. Special attention is given to sturdy turbine construction providing divided casing and slow-speed adjustable governor.

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Mixed Pressure Turbines

using exhaust steam from existing engines, have been found, in many cases, to increase the total output from 30 to 50 per cent, without any increase in fuel consumption. Special high pressure nozzles automatically come into action when the low pressure steam supply is insufficient for the power required.

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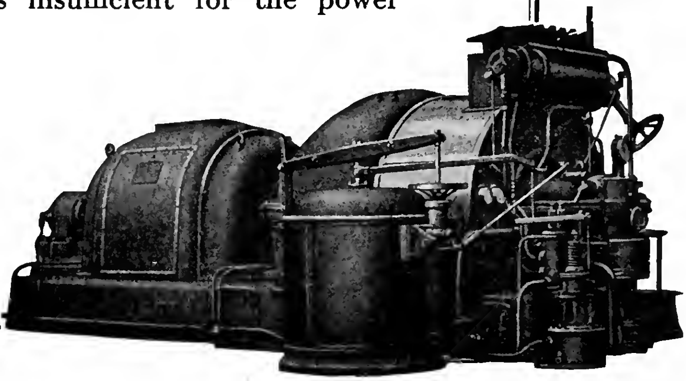

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE   Editor, JOHN R. HEWETT   Associate Editor, E. C. SANDERS

Subscription Rates: United States and Mexico, $3.00 per year; Canada, $3.25 per year; Foreign, $3.50 per year; payable in advance. *Library and Student Rates:* United States and Mexico, $2.00 per year; Canada, $2.25 per year; Foreign, $2.50 per year; payable in advance.

Remit by post-office or express money order, bank check, or draft, made payable to the *General Electric Review*, Schenectady, N. Y.

Advertising forms close on the first day of the month preceding date of issue.

Entered as second-class matter, March 26, 1912, at the post-office at Schenectady, N. Y., under the Act of March, 1879.

Vol. XXVI, No. 12   DECEMBER, 1923

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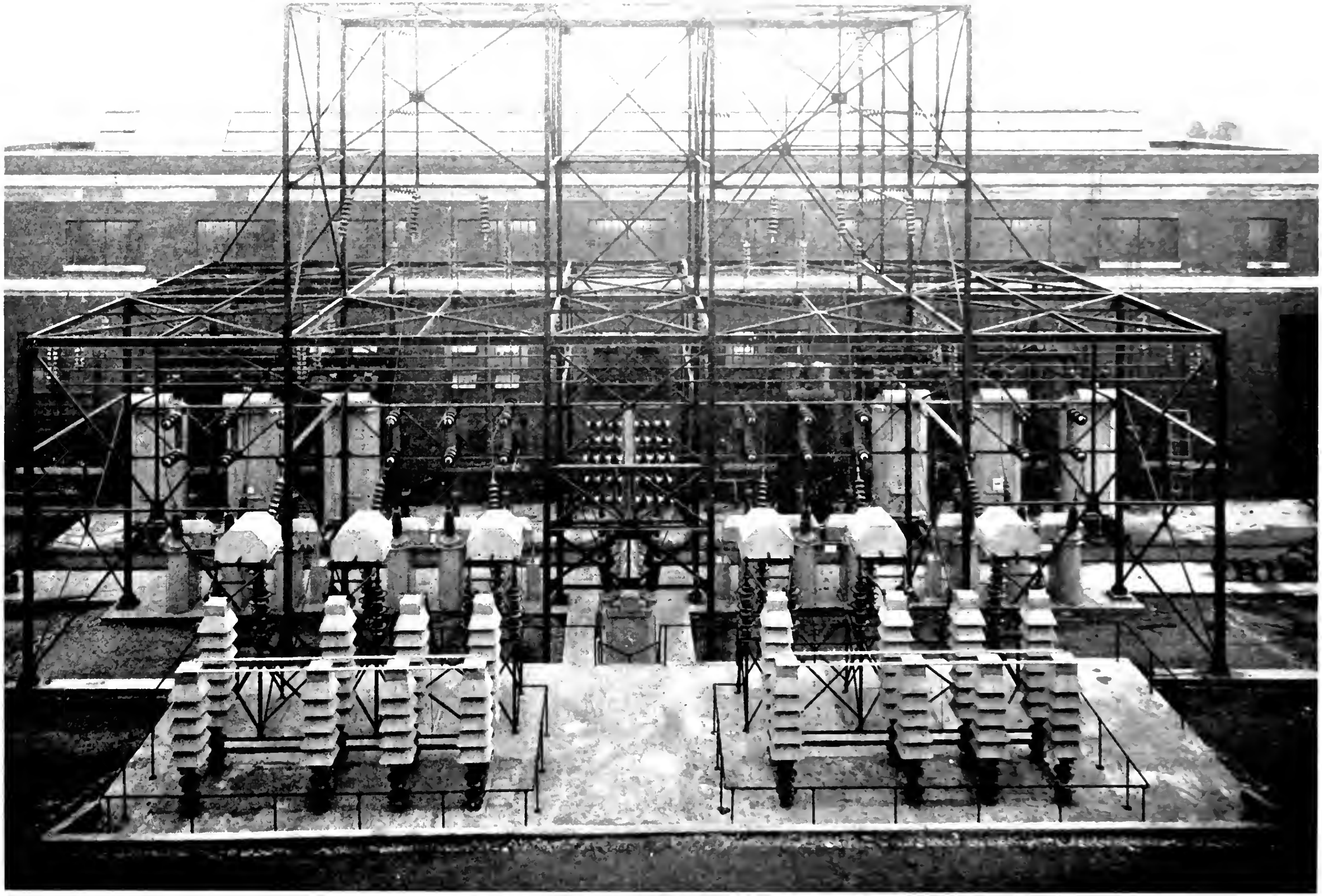


Outdoor Transformer and Switching Station of the Sherman Island Hydro-electric Plant on the Hudson River. The power house and six 7500-kv-a. 6600-66,000/114,500Y volt single-phase transformers (with one spare additional) are shown in the background. In the foreground are the high-tension oil circuit breakers and oxide film lightning arresters. (See page 804)

CHARLES PROTEUS STEINMETZ

1865-1923

His life was a service to mankind;
His death, a sorrow to the world

GENERAL ELECTRIC REVIEW

STEINMETZ

By the time our readers receive this copy of the REVIEW the sad news of Steinmetz's death will be a month old and most of them will have read some of the splendid tributes that have been paid to his great genius. Almost every paper in the land, and many of our foremost men, as well as our foreign contemporaries, have done him homage and we feel that it is a peculiarly hard task to add a fitting tribute.

So, recognizing our own inability to do the justice we should wish to the memory of this great man, we reproduce elsewhere in this issue an address delivered by Mr. E. W. Rice, Jr., at a memorial service held in Schenectady, on the evening of October 31st. Of the many tributes we have read there is none more authoritative or more fitting than this.

On the day of Steinmetz's death Mr. Martin P. Rice prepared a hurried address which he broadcast from WGY in the evening. We also reproduce this on account of the many pleasing personal touches.

As our readers know, Steinmetz was a great friend of the REVIEW and made many notable contributions to our columns, and, therefore, his loss will be an especially sad blow to us. But, at the same time as we mourn his death, we wish to rejoice at his life's work and to emphasize the fact that his achievements are destined to live forever as a perpetual tribute to his genius and as a lasting benefit to mankind.

Steinmetz was a peculiarly fortunate man in living such a useful life, because his strength lay in a great intellect, capable of clear and logical reasoning, with a natural bent for pure mathematics. His usefulness was based on his devotion of these high gifts to the solution of some of the most difficult problems confronting the electrical engineer. Had he been a rich man, and could he have followed his own bent in his own country, there is little doubt that he would have applied these gifts to the pursuit of pure mathematics. Had he done this it is possible that he might have lived and died almost unknown or, at least, known only to a few intellectuals and instead of the splendid contributions he has left us these might have been confined to a few papers, left on the dusty shelves of some museum or in the archives of some scientific societies, on such abstruse subjects as Poly-Dimensional Space and the Fallacy of Ether. Such papers have their value in stimulating the imagination of those who can read them, and, by a process of mental gymnastics, of exercising the mind of the writer, but they could never be compared with the contributions we have received from Steinmetz' brain.

The whole world knows the parable of the sower and how easy it is for some seed to fall on stony ground. And the world owes much to the fact that this giant mind in a frail body found a congenial soil in which to grow and flourish. It was indeed fortunate that this young immigrant of 1889 was not turned back at the gates of his land of promise and opportunity, and it is equally fortunate that he found, in his first place of employment, those who recognized his ability and guided his talents into fruitful channels. His coming into the organization of the General Electric Company at so early a date was a benefit alike to him, to the country, and to the wide world.

Steinmetz himself considered as his most useful work

(1) His investigations on magnetism.
(2) The development of his symbolic method of alternating-current calculations (complex quantities).
(3) His general theory of electrical transients.

Concerning his investigations on magnetism the whole scientific and engineering world knows his famous Law of Hysteresis, and many know of some of his other notable investigations in this direction, but few, who were not intimately familiar with contemporary engineering, can know or appreciate what this work did for the world electrical. Men had learned how to build dynamo-electric machines, transformers, etc., but they only knew how to build them by a cut and try method. Their knowledge was qualitative and not quantitative, and as Kelvin said "anything becomes a science only when we can measure it." Steinmetz taught us how to calculate the magnetic circuit and thus at once gave us the useful, efficient electrical machine. We know no words that can exaggerate the importance of this work to a then infant industry, and the far-reaching benefits it has conferred on the general public will remain largely unknown by them.

It is still harder to form an adequate conception of the value of his Symbolic Method of Calculating Alternating Currents. Most men who had attempted to calculate alternating-current phenomena became confused. It would hardly be an exaggeration to say that Steinmetz did for alternating-current calculations what the immortal genius of Newton had done for mechanical laws three centuries earlier—he brought order out of chaos. He put a tool into the hands of other men which enabled them to work successfully in a field which hitherto had been too strewn with rocks to plant.

His symbolic method so simplified the treatment of many complicated phenomena that its use soon spread. First it became generally used in America, and then the whole world adopted it. He advanced the progress of civilization by this contribution to our knowledge. To what degree this work brought forth useful fruit will always be unknown, but will probably always be underestimated. When the work of one genius enables an unnumbered host to do more fruitful work the result is something like a snowball rolling down hill; it gets bigger and bigger. Who can determine how long it will roll? Who can determine how great it will become?

It was largely by the results of this work of Steinmetz that the path was made clear for transmitting large alternating-current powers over long distances. These accomplishments stimulated his dream that some day the country would be covered with a veritable network of high tension transmission lines, which would transport electric energy to every corner of the land in the same way as our railways convey materials.

With the growth of transmission lines, "our old enemy, lightning" (using his words) became a terror to the electrical engineer. Steinmetz with characteristic energy studied the phenomena of lightning and propounded his General Theory of Electrical Transients. In brief, he found that it was not the actual stroke of lightning that did the most damage, but the great brief surge, or transient, as he termed it, which was produced by the machines in circuit, when they get out of control due to the lightning stroke. With this knowledge he tackled the problem of protecting transmission lines and machines against lightning and its attendant transients, and the modern lightning arrester is largely the result of his work.

The name of Steinmetz could be conjured with, and as is only natural it was the spectacular elements in some of his undertakings that fired the imagination of the public, rather than the true significance of the work.

His lightning generator thrilled a continent and he was heralded as the wizard of Schenectady, who had outdone Jove in making lightning bolts. But his lightning generator was no instrument of destruction; its purpose was to teach us means and ways of making apparatus to protect against lightning.

The great work that Steinmetz was so busy on during the last few years of his life and up to the time of his death, was a study of the mechanism of electric breakdowns in air, oil and solids. He himself thought that the importance of this would outrank most of his other work. He was trying to determine just what happens at the instant of a breakdown when the insulation fails; and his lightning generator was the instrument he was using to create the high powered transients he needed for experimental purposes in the design of lightning-proof, and transient-proof apparatus.

Steinmetz was above all things a mathematical genius, and Steinmetz the mathematician was greater than either Steinmetz the inventor or the author. But he has some 200 patents to his credit, which might well make many other inventors envious; while his books on electrical subjects are the textbooks of the world.

As a teacher it is hard to place him—only because it is difficult to reach the height. His life would still have been well spent had it been devoted to teaching. His clearness of vision and precision of thought were brought out to the nth degree when explaining complicated problems to minds less brilliant than his own. We know no one who could explain a problem in as few words as Steinmetz. His value as a teacher will never be computed. He taught others the fundamentals of mechanical as well as electrical engineering, and again his pupils taught yet others, and so on. He took a keen interest in education in general. He was a power in educating others and at the same time a power among educators. If we take a seed and drop it in the ground and then take all it produces and plant again, and so on, for a period of years, who can estimate the value of the original seed? So it is with the value of Steinmetz' work as a teacher—we cannot estimate it.

As a lecturer he had few equals. The English language was not his own, but his clearness of expression, his conversational delivery, and his charm of manner endeared him to his audience. The public came to learn and coming learned to love.

Had we the wit and wisdom we would try to tell you something of the *Man*, Steinmetz—as well as touching on him as the mathematician, scientist, engineer, inventor, teacher and lecturer, but we feel that we must leave this to a more ready pen.

However, we have many pleasant recollections of the *Man*. We remember some years ago dropping in one evening to have a chat with "The Doctor." He took us to his conservatory which was filled with cacti and strange creatures, and we remember now the interest with which he talked on the struggle for life in the desert. We had seen the cactus growing in its own native wildness in the deserts of New Mexico, Arizona and California; and had met the Gila monster in its own home, in that most uncharitable of all spots, the Apache Trail. So we could appreciate his interest in the great struggle to survive, and how such ugly things as the poison of the rattlesnake and of the Gila monster, and the spine of the cactus were necessary weapons to protect life in such a seemingly unfair fight.

And, as we looked at the Doctor, we could but realize that, with all his brilliancy, there must have been a great barren space in his own life. As the little cripple boy of Breslau and as the young man, he must have realized, as his mind unfolded, that many chapters in a complete life must forever be closed to him. The joyful spirit of youth, which he maintained to such an extraordinary degree all through life, could find no outlet in athletic sports, and the handicap that was placed upon him from the start prevented a lover of children from marrying and having a family of his own.

Many minds less noble than the Doctor's would have cultivated the poison of the serpent and the spine of the cactus in such a struggle. But not he. And herein lies the greatest triumph of his life. He chose love instead of venom as a weapon. He turned his barren spot into an oasis and planted it with flowers. And like the blossoms of the cacti in the desert, the flowers he planted were more beautiful than the lily and more fragrant than the rose; because they grew where only God knew flowers could grow. To the man in a desert one bloom, unfolding its petals to heaven, is more precious than unnumbered roses in a garden. In the one place you expect flowers, in the other thorns.

The Doctor adopted a son who lived and raised his family in the Doctor's home and his son's children were as his children.

It was a character that could thus turn defeat into victory and build a home of love upon a quicksand that made Steinmetz one of the unique figures in history. The public who did not and could not understand his work regarded him as their idol. He was respected and loved by more than one continent. He added lustre to the fame of the town he lived in and honor to the country he adopted.

In the fulness of his greatness he loved children—and children loved him—and so on the day of his funeral every school in Schenectady was closed. We, and the children, can't bear think of him as gone; so will ever remember his work as living rather than him as dead.

To Charles Proteus Steinmetz, the great mathematician and multigifted genius, we render homage and proclaim that his work will live forever, as a flaming beacon to light the paths of men and guide their feet.

But to Steinmetz—the Friend of Children—the lover of animals and birds and flowers—the congenial comrade, calling him by the name the little children called him, we blow a kiss into the air and call out "Good Bye! 'Daddy' Steinmetz. God bless you."

J. R. H.

Charles Proteus Steinmetz

HIS SCIENTIFIC ATTAINMENTS AND THEIR MEANING TO THE WORLD

By E. W. Rice, Jr.

Honorary Chairman of the Board, General Electric Company

Among the most pleasing tributes Schenectady paid to Charles Proteus Steinmetz was a memorial service held on the evening of October 29th. On this occasion Mr. Rice, a lifelong friend and associate, read the principal address. As Mr. Rice was one of the first to recognize the genius of our illustrious citizen and was largely responsible for his coming to the General Electric Company, we publish this address in full for the benefit of our readers, feeling that it is the most authoritative tribute we have read.—Editor.

The whole world, through its orators and writers, has expressed so beautifully and so well its appreciation of Charles Proteus Steinmetz, that if I attempted to express what is in my heart, it would be but to repeat what has already been said much better by others. However, as his devoted friend and intimate associate for one-third of a century, as one who recognized his great talents when he was unknown, and surrounded him with a favorable environment for the development of his genius, I regard it as a privilege to publicly endorse all that has been said of his usefulness, his commanding genius, his inspiring personality. This cheerful, patient, kindly spirit, this zealous student of nature and lover of humanity, was your friend and my friend.

I have been asked to speak of his scientific attainments and their meaning to the world. To do this properly would be to cover much of the history of the electrical industry during the past 30 years. I must confine myself to sketching such features as seem of most importance, and possibly of greatest interest.

Thirty years ago I first met Steinmetz.

The General Electric Company had been recently formed by the union of the Edison Company and the Thomson-Houston Company, which brought into one enterprise the results of the work of Edison, Elihu Thomson, and many other early pioneers in the fields of arc and incandescent lighting, electric traction, and industrial motor application.

Rudolph Eickemeyer of Yonkers had developed some interesting designs for electric traction purposes, and certain novel and economical forms of windings for armatures of electrical machines. I was then in charge of the manufacturing and engineering of our Company and my views were sought as to the desirability of acquiring Eickemeyer's work. I remember giving hearty approval, with the understanding that we should thereby secure the services for our Company of a young engineer named Steinmetz. I had read articles by him which impressed me with his originality and intellectual power, and believed that he would prove a valuable addition to our engineering force.

I shall never forget our first meeting at Eickemeyer's workshop in Yonkers. I was startled, and somewhat disappointed by the strange sight of a small, frail body surmounted by a large head, with long hair hanging to the shoulders, clothed in an old cardigan jacket, cigar in mouth, sitting crosslegged on a laboratory work table. My disappointment was but momentary, and completely disappeared when he began to talk. I instantly felt the strange power of his piercing but kindly eyes, and as he continued, his enthusiasm, his earnestness, his clear conceptions and marvelous grasp of engineering problems convinced me that we had indeed made a great find. It needed no prophetic insight to realize that here was a great man, one who spoke with the authority of accurate and profound knowledge, and one who, if given the opportunity, was destined to render great service to our industry.

I was delighted when, without a moment's hesitation, he accepted my suggestion that he come with us.

Steinmetz had already made his first important contribution to electrical science in investigations of magnetism, and especially in formulating and determining the laws governing the losses in iron subjected to varying magnetic induction. He showed that the hysteresis varied as the 1.6 power of the density of magnetic flux. This made possible for the first time the exact predetermination of the so-called iron losses in the armatures of electric motors and generators and in the transformers and other electrical apparatus employing iron. As a result, the quality of our electrical machinery was improved, and the weight and costs reduced. It is difficult at this date to realize the fundamental importance of this one contribution to the orderly and definite progress of the electrical industry.

During most of the first decade of the commercial application of electricity to light and power which may be said to cover the period between 1880 and 1890, direct current only was used. This was the basis of the Edison system, the Thomson-Houston arc system, the Vanderpool and Sprague railway motor systems. The laws governing the flow of direct current were simple and easily understood, and could be treated by mathematics of the most elementary character.

About the time Steinmetz came with the General Electric Company in 1893, the use of alternating current for lighting, power, and other purposes was just beginning to be of demonstrated commercial value. Advance in the commercial use of alternating current was hindered by the extreme difficulty of understanding the technical nature of its action and of the various phenomena connected therewith. The engineer who had been working with direct current found it difficult to understand, and therefore to correctly design alternating-current apparatus. While the problems of the direct-current apparatus and electric circuits could be treated by the simplest mathematics such as ordinary arithmetic, the alternating current, involving such phenomena as reactance, capacity, leading and lagging currents, phase displacements, etc., could apparently only be solved by higher mathematics involving the use of calculus—methods which were not generally familiar to the engineers of those days. Even skilled mathematicians familiar with such methods made slow and difficult progress in the solution of the problems which arose daily.

Steinmetz took hold of this situation with characteristic energy, and soon brought order out of chaos. He abolished the mystery and obscurity surrounding alternating-current apparatus and soon taught our engineers how to design such machines with as much ease and certainty as those employing the old familiar direct current.

He had already made the discovery that alternating-current problems could be attacked and solved with success by the use of what was known as complex quantities. By the use of this system he not only was able to solve these problems himself, but to teach our engineers to do the same work by methods almost as simple as ordinary arithmetic and algebra. Steinmetz himself always regarded this as one of his greatest contributions and called it the development of the "Symbolic Method of Alternating-current Calculations." This method was found to be so powerful, accurate and rapid that its use was not confined to the engineers of our Company, but rapidly spread throughout the world. He preferred to use this mathematical method in the treatment of all the problems of alternating-current engineering which arose and advocated its use before the American Society of Electrical Engineers in numerous papers, and embodied it in the textbooks of which he was author.

Not only did the adoption of these mathematical methods open the door to many to do useful design work who otherwise could not have done so, but it enormously increased the speed with which definite and accurate calculations and designs could be made. It furnished the engineer with a powerful tool which multiplied his power with just as much certainty as the machine tool improves and multiplies the usefulness of the ordinary workman.

It was fortunate indeed for our Company and for the electrical industry that Steinmetz became associated with us at the critical time when the alternating-current development had just started. It is not too much to say that his genius and creative ability, not only in his own personal work, but in advocating and obtaining the general use of a simple mathematical system (for treatment of alternating-current problems) was largely responsible for the rapid progress made in the commercial introduction of alternating-current apparatus.

Steinmetz's practical inventions literally cover the entire field of electrical applications: generators, motors, transformers, lightning arresters, lighting, heating and electrochemical operations. Of these many inventions, which were set forth in some 200 patents, perhaps the most important are the induction regulator, the method of phase transformation, as from two-phase to three-phase, and the metallic electrode arc lamp.

His experimental work in arc lighting led to the production of the magnetite arc. The practical advantage of this type of lamp is found in the extreme length of time which the metallic electrode will burn without recharging—these electrodes burning 200 hours contrasted with a life of 70 hours in the carbon arc used before his time. The efficiency also of this type of lamp, especially in small units of illumination was of great commercial value.

He devoted much time to the development of the mercury arc and by his masterly methods did much to improve this interesting and important type of illumination. These and many other of his inventions have found permanent and extensive use in the industry.

During the last ten years when alternating-current power transmission lines of great length, carrying large amounts of energy, have spread all over the country, to use his own words—"an old enemy became more and more formidable—lightning, and for many years the great problem which pertained to the successful development of electrical engineering was that of protection from lightning. Before this could be undertaken with reasonable hope of success we must know a great deal more about lightning and centered phenomena. This led to the investigation of transient phenomena. It was soon found that while lightning might have been the criminal which started the trouble in the electrical system, the damage and destruction was not done by lightning, but by the electric machine power back of the circuit which was let loose and got out of control by the disturbance initiated by lightning." He goes on to say that "the study of the phenomena produced by lightning effects could in general be grouped under the name of 'transients' because, unlike the direct and alternating currents which flow continuously, these disturbances last a limited time only."

The study of this problem led him to produce his famous "lightning" generator of which so much has been told in the public press. In the hands of Steinmetz and his assistants such progress has been made that the nature of the phenomenon has been so elucidated that as a result it is possible to proceed with confidence in the further development of the large high powered transmission systems, making possible Steinmetz's vision that the day was rapidly approaching when the electrical engineer would supply the world's requirements of energy over transmission lines which would cover the country with a network similar to that of the railways, the one taking care of the distribution and supply of energy, and the other carrying the materials.

Steinmetz was an ardent believer in the value of education. He not only found time to aid the educational work of Schenectady, but became President of the National Association of Corporation Schools, and lecturer at Union College. In a masterly address, upon retiring as President of the A.I.E.E. in 1902, he stated that "all future progress in science and engineering depends upon the young generation, and to insure unbroken advance it is of pre-eminent importance that the coming generation enters the field properly fitted for the work."

His personal example, his spoken words, and his writings have had a powerful and beneficial influence upon the development of education, especially technical education in this country.

That I have not overstated the value of Steinmetz's work in the early period is indicated by the message of an eminent electrical engineer, Prof. Harris J. Ryan, President of the American Institute of Electrical Engineers, who says: "Through a period of years Dr. Steinmetz stood almost alone as the one electrical engineer in the world capable of defining and solving the many perplexing problems encountered for the understanding and improvement of the transformer, induction motor, alternator and polyphase high voltage system, the modern fundamental implements of the electrical engineer."

That the value of Steinmetz's services was not limited to the General Electric organization is well known, but it pleases us to have the testimony to that effect by President Herr of the Westinghouse Electric and Manufacturing Company, who states: 'He has been such an outstanding figure in engineering work for so many years and is so well known to the public that his death will be a great loss not only to the profession but to people generally."

One of our largest customers offers the following tribute:

"He was untiring in his devotion to the development of the electrical industry and in his passing the industry has suffered an irreparable loss."

From far Japan comes the following comprehensive and beautiful encomium: "He spent his life serving humanity."

A representative of the greatest electrical manufacturing company in Germany offers the following tribute:

"It will always remain one of the highest merits of your Company that he found here the congenial environment and support necessary for a genius like his to develop to the fullest benefit of mankind."

Edison says:

"I regret very much to learn of the death of Charles P. Steinmetz. The world has lost one of its greatest practical mathematicians, and the electrical industry will miss one of its shining lights."

Professor Elihu Thomson, one of our country's greatest scientists and electrical engineers, a man whom all the world delights to honor, sends this tribute:

"In the death of Dr. Steinmetz, the science of electrical engineering has lost a great leader, whose talents were most exceptional. Nearly a third of a century has passed since he displayed a faculty amounting to genius in the application of mathematical methods to the solution of difficult problems in electrical work, and throughout the subsequent period this special work of his has been followed up unremittingly. His numerous books and papers, his lectures and discussions will in themselves constitute an imperishable monument for all time. His long connection with the General Electric Company gave him the needed opportunity to put into extensive practice his ideas, and the resulting value to the industry itself cannot be measured or estimated. The whole science of transient phenomena in electric circuits is virtually his; and he had the qualities of the patient teacher and expositor to those seeking information as students or listeners to his discourses. Only those who have followed his career, so full and so fruitful, can know the vacancy created by his absence from among us."

I must now bring to a close this inadequate sketch of the contributions of this remarkable man to the development of the electrical science and industry. During his short life he rendered services of the most conspicuous character and inestimable value.

He was the author of many original scientific papers and of a large number of electrical books which have been the accepted standards in colleges, laboratories and workshops everywhere.

He was a prolific inventor, a skilled mathematician, a trained engineer, and an inspiring teacher. Our generation has produced men who have equalled or excelled him in some one of these fields, but no one has arisen who, to such a superlative degree, combined the qualities of inventor, mathematician, engineer and teacher.

He possessed a marvelous insight into scientific phenomena, and unequalled ability to explain in simple language the most difficult and abstruse problems.

Countless electrical engineers now occupying positions of great importance in our Company and elsewhere in the world gladly give testimony of their debt to him.

He was patient, sympathetic, cheerful, and ever willing to share his great gifts with all those who sought his counsel.

He loved children and they loved him. A neighbor and his wife were mourning his loss in the presence of their children, when the father exclaimed with deep emotion, "and he was my friend." His little son of seven years looked up from his play and said, "He was my friend too, daddy."

We, his fellow citizens, friends and associates, join the great world in mourning his loss, but may our grief be tempered by the memory of his great achievements which make his name the synonym of high service to humanity.

Dr. Charles Proteus Steinmetz

By Martin P. Rice

Manager Publication Department, General Electric Company

We shall hear and read much about Steinmetz as the great mathematician, engineer and inventor but not so much about him as the man; and it is the human side of this great genius that makes such a strong appeal to us. Mr. M. P. Rice wrote a hurried tribute on the day of Steinmetz's death and broadcast it over WGY in the evening. We publish this quickly prepared tribute because of its many human touches.—Editor.

Some years ago Dr. Charles Proteus Steinmetz was warned of a valvular trouble of the heart, but it made little difference in the energy which he devoted to his favorite studies and investigations. Last night he was reading a scientific work on the physics of the air. This morning we learned the sad news of his death.

A large part of the world recognized him as an outstanding genius in the realm of electrical engineering and mathematics—a worker of spectacular wonders—the superman of an electrical age.

To a few, however, it was given to know him as a friend and companion of winsome charm—intensely human in his fine appreciation of Nature—happy in the fellowship of children—loving to animals, and trustful of his fellowmen.

In the scientific world he was a recognized master of mathematical calculation and theory as well as a genius in the practical application of abstract principles to the design of electrical machinery. A creator of complex formulae, he possessed the rare gift of translating them into phrases which could be understood even by young students of electrical engineering.

Dr. Steinmetz was no recluse. Where another man of like attainments might have preferred to remain in the isolation of a laboratory, he went forth to meet men—partly through his many published text books and treatises, and partly through a personal interest in public affairs. The master of scientific attainment was also a daring publicist and participant in matters of economic interest.

Let me briefly review the career of one who reached the shores of America almost penniless and without knowledge of the English language and who, at the end of five years was actively engaged in the design of the General Electric Company's apparatus and in its scientific research. More than this he had appeared before the American Institute of Electrical Engineers and had propounded principles that fairly astonished that learned body.

Dr. Steinmetz was born at Breslau, Germany, April 9, 1865. He studied mathematics, physics and kindred subjects at the University of Breslau. It is curious to relate of this great mathematician that in his younger years he experienced the greatest difficulty in learning the multiplication tables.

Ever an ardent student of public affairs—ever refusing to be bound by tradition or authority, he espoused the cause of Socialism while at the University and so fell under the ban of the German government. He was forced to leave the University and to flee the country to avoid arrest because of his convictions. In Switzerland he found a refuge where he continued his studies and made a scanty living by writing and teaching.

Here he heard the call of America—a summons that has reached the ears of many a great man with its promise of intellectual freedom and of opportunities for scientific recognition. An American student at the Polytechnic at Zurich, who had formed a close friendship with the eager German and who was compelled to return to America, persuaded Dr. Steinmetz to accompany him to the Land of Promise—first by emigrant train and then in the steerage of an ocean liner. Thus there arrived at Castle Garden in New York the scientist whose death is now being mourned, whose loss to the world of electrical science is now being deplored not only by those competent to appreciate his contribution to the development of electricity but by the multitude who took pride in the accomplishments of his unusual genius.

Within two weeks the man who had narrowly escaped rejection at the hands of the immigration officials was devoting his talents to the improvement of electric street cars in the employ of Rudolph Eickemeyer at Yonkers, N. Y. This was one of the most important creative fields in the electrical industry at that time, and the unknown immigrant at once showed his mastery of electrical theory and practice. Soon he was writing on electrical subjects—more especially the laws of magnetism—with an authority and vision that compelled attention among America's foremost electrical engineers.

When the comparatively small Eickemeyer business was purchased by the General Electric Company in 1892, Dr. Steinmetz was recognized as the most precious part of the transaction and was established at the Lynn Works. He was soon transferred to Schenectady and became a fixed star in the electrical firmament. As a consulting engineer of the General Electric Company his knowledge of electrical phenomena and the mathematical laws governing them were of invaluable service. Other engineers discussed their problems with him and invariably profited by his wisdom and inspiration.

Meanwhile special honors awaited the mind that had been expelled from Germany. President Eliot of Harvard University, in conferring the degree of Master of Arts on Dr. Steinmetz in the year 1902, said: "I confer this degree upon you as the foremost electrical engineer in the United States, and therefore the world." In 1903 he received the degree of Doctor of Philosophy from Union College at Schenectady with which he has since been connected as Professor of Electrophysics. He has been President of the American Institute of Electrical Engineers, of the Illuminating Engineering Society, and of the National Association of Corporation Schools, and has received recognition in many foreign lands.

Dr. Steinmetz accounted as one of the most important of his accomplishments his investigations in the field of magnetism. Before he addressed himself to this important part of electrical theory, much apparatus had been built in the hope that it would operate economically or to quote Dr. Steinmetz's own words: "The designer of electrical apparatus simply built it, then tested it, and when the loss was too high and the efficiency too low, or the machine too hot, he tried again. This obviously was not a satisfactory way."

Steinmetz's famous paper which astonished the American Institute of Electrical Engineers in 1892, established basic principles that afford data for all future design.

Dr. Steinmetz's investigations into the theory of direct and alternating current were so far ahead of the knowledge of his time that when his views were developed by him before the International Electrical Congress held at Chicago in 1893, many of his hearers were unable to follow him and it was only after several years that his investigations took printed form. Thirty years ago Steinmetz stood almost alone in his knowledge that has since been embodied in accepted engineering practice.

The third of the fields of investigation which Dr. Steinmetz adjudged the most important in his life work was the study of the phenomena of lightning. The world knows of his artificially developed lightning bolts, but the world does not know of the painstaking study which he bestowed on the protection of electrical apparatus not only from natural lightning but from the disturbances which it set up in electric circuits and machinery.

These accomplishments may not mean very much to the lay mind, but to the electrical engineer and manufacturer they have marked epochs in the development of the industry.

The unassuming figure without hat or overcoat, that was so well known about the streets of Schenectady, was literally a world power. To him every country looked for authoritative dicta on all matters of electricity. The man who welcomed friends to his summer camp with an almost boyish glee, whose kindly soul went forth in the fondling of a favorite dog, whose life and likings were the most simple—this man was an international figure, a giant in his profession, a conservator of the world's natural resources, and a friend to every user of electricity.

We mourn his passing, but we are deeply grateful for the wealth of knowledge that he has contributed to the world's progress, and we treasure as a choice possession the memory of an earnest, simple man who devoted his transcendent mind and talents to the service of his fellow men.

Charles A Coffin Medal Railway Award

By R. D. Owen

Publication Department, General Electric Company

In recent years we have heard more of criticisms than of praise concerning our electric railways; but many of our roads have been by no means lax in making improvements. The electric railway industry has been through hard times owing to the changed economic status caused by the war, but the fact that some roads have made as much progress and as many improvements as have been achieved in any part of the electrical industry is well brought out by some of the speakers at the recent convention of the American Electric Railway Association held at Atlantic City. The brief submitted by the North Shore Line in competition for the Charles A. Coffin Medal is an eloquent tribute to what a progressive policy can do in turning apparent failure into a conspicuous success.—Editor.

The Chicago, North Shore and Milwaukee Railroad has been awarded The Charles A. Coffin Medal for "its distinguished contribution during the past year to the development of electrical transportation for the convenience of the public and the benefit of the industry." This was the first award to an electric railway by the Charles A. Coffin Foundation, established by the General Electric Company in honor of its founder.

There are four classes of annual awards made by the Foundation for the encouragement of those in various branches of the industry, and it was the hope, now thoroughly justified, that the railway award would be an inspiration to railway managements by marking the progress from year to year toward better service to the public and high standards of operation.

Indeed, C. D. Emmons, former president of the American Electric Railway Association, who announced the award at the annual convention of the Association at Atlantic City, October 11, said that alone it justified the existence of the Foundation because of its service in bringing before the industry the record of electric railway accomplishments. He saw in it the means of stimulating initiative by giving recognition and honor to great achievements.

The Chicago, North Shore and Milwaukee Railroad won the prize this year because of its outstanding work in giving and selling service to the public. There were many close contenders for the award, but the attainments of the North Shore Line, as it is called, were so great that there was no doubt in the minds of the prize committee as to where the award should go. The accomplishments of other railways was something of which the industry might well be proud, and Mr. Emmons said that their contributions would be published so that they might be known generally throughout the industry. Seventeen roads sent in briefs in support of their claims to recognition, and they presented impressive evidence of the desire of electric lines to give service.

The committee which made the award was made up of C. D. Emmons, president of the United Railways & Electric Co., of Baltimore; J. H. McGraw of the McGraw-Hill Co., New York; and Britton I. Budd, president of the North Shore Line. When it was found that the decision was narrowing down to a small group of which the North Shore Line was one, Mr. Budd withdrew from the committee. J. G. Barry and A. H. Jackson, vice-presidents of the General Electric Company, acted in an advisory capacity.

The announcement was made in the Greek Temple on the Million Dollar Pier, where the Association held its meetings. The room was well filled when Mr. Budd went up to the platform to receive the medal from Mr. Emmons and to hear an appreciation of his services and the high standing attained by the North Shore Line. Many things which had been talked about for years, said Mr. Emmons, had been carried to fruition on the North Shore Line, the committee being particularly impressed by the work in gaining good will and selling service.

Mr. Budd was smiling with gratification as he took the medal and the certificate which accompanied it, and expressed his appreciation and thanks for the recognition given his line. Whatever had been done, he said, had been done by the concerted effort of directors, officers and employees.

"We have teamed as one in the common purpose of endeavoring to give service and win the approval of the public," he said.

It was a striking coincidence that Mr. Budd was also elected President of the Association to succeed Mr. Emmons. He has long been one of the outstanding figures in electric railway operation. He is one of the few men in the country who understands thoroughly interurban, street railway and rapid transit operation.

He has been associated with transportation ever since he left school, when he took a position with the surveying department of a steam railroad in Ohio. In 1893, during the World's Fair at Chicago, he was associated with the Intramural Railway. When the Metropolitan Elevated was started in Chicago, he foresaw the city's transportation development, and obtained a position in 1895 as clerk in the storehouse. His advance was rapid and in 1910 he became president of the company. When all the elevated lines in Chicago were consolidated in 1911 he was chosen president of the combined system. When the Chicago, North Shore and Milwaukee Railroad was reorganized in 1916 he was selected as the man to straighten out the tangled affairs of that rundown and dilapidated property. How well he did his work is evidenced by the award.

The medal was accompanied by $1000 for the Employees Mutual Benefit Fund of the North Shore Lines. It was accepted by Louis Homans, president of the fund, on behalf of the employees, who said that it would not only be a substantial contribution to their fund, but would inspire the employees to greater effort in making the North Shore Line a synonym for courteous and efficient service.

The accomplishments of the line were summarized in the brief presented in its behalf in the following words:

"From a railroad patronized only as a necessity when other means of travel were not readily available, it has become 'the most talked about electric railroad in the country,' and is patronized by thousands of travelers in preference to any other means of transportation in the territory through which it runs.

"How was this accomplished?

"The answer may be epitomized in a single sentence: By giving service and telling the public its story."

The equipment was in a rundown condition after ten years in the hands of receivers, only such work as was needed to keep the cars running had been done. Service was worse than poor. This was all changed. A frequent local service was begun, and fast non-stop trains making a mile a minute were run between Milwaukee and Chicago. Trains were run even when the patronage did not at first justify them. The policy of additional service without waiting for requests from patrons was held to consistently. The best types of cars were provided, some of them luxurious observation parlor cars. They were well heated and ventilated.

This service was then sold to the public. Every courtesy and assistance was offered to shippers. Newspaper advertisements, attractive posters, bulletin boards and motion pictures were used to carry the message of service. Every employee was made a salesman of service, and their courtesy is the result of pride in their road. So many things were done to obtain the good will of the communities, through which the road ran, that the things done became "news" which the newspapers were glad to publish.

Economy in operation was sought, but not at the expense of the public. Automatic substations were used extensively, and the power system improved in every possible way. Power consumption was reduced by better equipment and through the co-operation of employees. Labor saving devices were used wherever possible.

Improved construction played a big part in winning public good will. Handsome stations were erected, roadbeds made as smooth as possible by rock ballast and heavy rails, wooden platforms were eliminated, even the grade crossings were made smooth so that motorists would not be bumped when they crossed the line. Accident prevention work was done among employees and the public was educated by lectures, posters and other means. First aid drill teams were organized among the employees.

The relations between the employees and the management have been carefully cultivated. They have been made to feel that the road is their road and to have a pride in its operation. The financial problems of public utilities have been put clearly before them. Financial assistance was given to students, public speaking classes were encouraged. Americanization work was undertaken with the idea of making better citizens. Home building was encouraged. Employees were not discharged because they did not fit in a job; they were shifted until it was found what work they could do well. Suggestions from employees were sought and rewarded.

The Sherman Island Hydro-electric Development of the International Paper Company

By B. R. Connell and By W. T. O'Connell
Industrial Engineering Department, General Electric Company
Construction Engineering Department, General Electric Company

The construction of a hydro-electric plant at Sherman Island in the Hudson River presented an unusually difficult problem, as described in the following article, and great credit is due the engineers for the ingenious features of design which have made possible this development. The output of the station will be distributed throughout the extensive system of the Adirondack Power and Light Corporation, which is tied in with the New England Power Co. on the east, the United Hudson Gas and Electric Co. on the south, and the Utica Gas and Electric Co. on the west, all of which will benefit by this further conservation of the waters of the Adirondacks.—Editor.

Civil, mechanical, and electrical engineering put into form by high-class craftsmanship in many trades has created the Sherman Island Hydro-electric Plant of the International Paper Co.

Four of the five ultimate units of this 50,000-h.p. development on the Hudson River a few miles west of Glens Falls, N. Y., were recently put into operation. The power is transmitted to the main trunk system of the Adirondack Power and Light. Corporation, purchaser of the entire output.

This unusual generating station is located where the Hudson River emerges from the mountains at the edge of the great plain of glacial fill east of the Luzerne Range. Fig. 1 shows the location, general plan, and contours. The pond extends back to the tailrace of the Spier Falls plant of the Adirondack Power and Light Corp. and the tailrace discharges to the pool of the Barge Canal feeder dam at the western edge of Glens Falls. The maximum flow is about 117,000 sec-ft. and the plant is designed for 7600 sec-ft. at 66 ft. head. The installation of the fifth 9000-kw. unit will await flow regulating developments along the head waters and tributary streams.

The general design was made by A. H. White, chief engineer of the International Paper Co. and in general charge of the work. H. de B. Parsons was consulting engineer and designer of the main dam. The construction work was done by the Parklap Construction Corporation. The waterwheels were built by the I. P. Morris Dept. of Wm. Cramp and Sons. The entire electrical equipment and electrical layout was furnished by the General Electric Company.

Dam

The river at this point flows between the granite and sandstone shoulders of Luzerne and Palmertown Mountains and over a boulder and gravel fill 550 ft. wide and of unknown depth. The banks on either side east of the dam site are of gravel and fine sand.

There are four structures to the dam and they are: (from south to north) the spillway, the main dam, the wing dam, and the head gates.

Spillway

The spillway is a horseshoe-shaped gravity-type dam on solid rock, all upstream from the main dam and 175 ft. wide at the opening of the horseshoe. Fig. 3, a view from the south end of the main dam, shows the larger part of the 864 ft. of weir which is at elevation 350.5 ft. and 11.5 ft. below the crest of the main dam. With the pond level 2 ft. below the crest of the main dam 100,000 sec-ft. can be discharged by the weir. Sluiceways provided for construction use are retained for possible lowering or draining the pool.

Main Dam

The main dam is of special interest as it is of the hold-down type built entirely upon the boulder and gravel river bed. It is 551 ft. long with its crest at elevation 362 ft. The walkway is 70 ft. above the bottom of the great longitudinal ribs under the slab. Fig. 2 shows its general appearance though its height is partly concealed by the 20-ft. sand fill on the slab.

This dam is made up of arches across the upstream sloping sides of some 30 buttresses which in turn rest on a slab 104 ft. wide and 3 ft. thick. The buttresses are 3.5 ft. thick and are spaced 15.5 ft. face to face. The slope is in two pitches, the lower two-thirds being 5 to 12 with arches 24 in. thick and the upper third 12 to 12 with arches 18 in. thick. The floor slab is reinforced and insured against slippage by three longitudinal ribs 9 ft., 10 ft., and 6 ft. deep. An apron 50 ft. wide and 2 ft. thick extends downstream from the slab. The slab and apron are covered by 20 ft. of sand for additional weight. Fig. 4 shows the massive concrete work in the upper portions of the dam.

Seepage under the dam is minimized by two interlocking steel piling barriers driven

55 ft. deep and sealed into the upstream edge of the slab. The pond bottom for some distance upstream was covered with fine sand to stop the interstices of the bottom. Overturning is prevented by the broadness of the base and the slope of the upstream side which puts about 55 ft. of static head on the upstream toe.

Wing Dam

The wing dam is of solid concrete on rock connecting the main dam with the headgate structure, and tapering off as a reinforcement into the river side wall of the power canal. It is 171 ft. long and of the same type as the spillway.

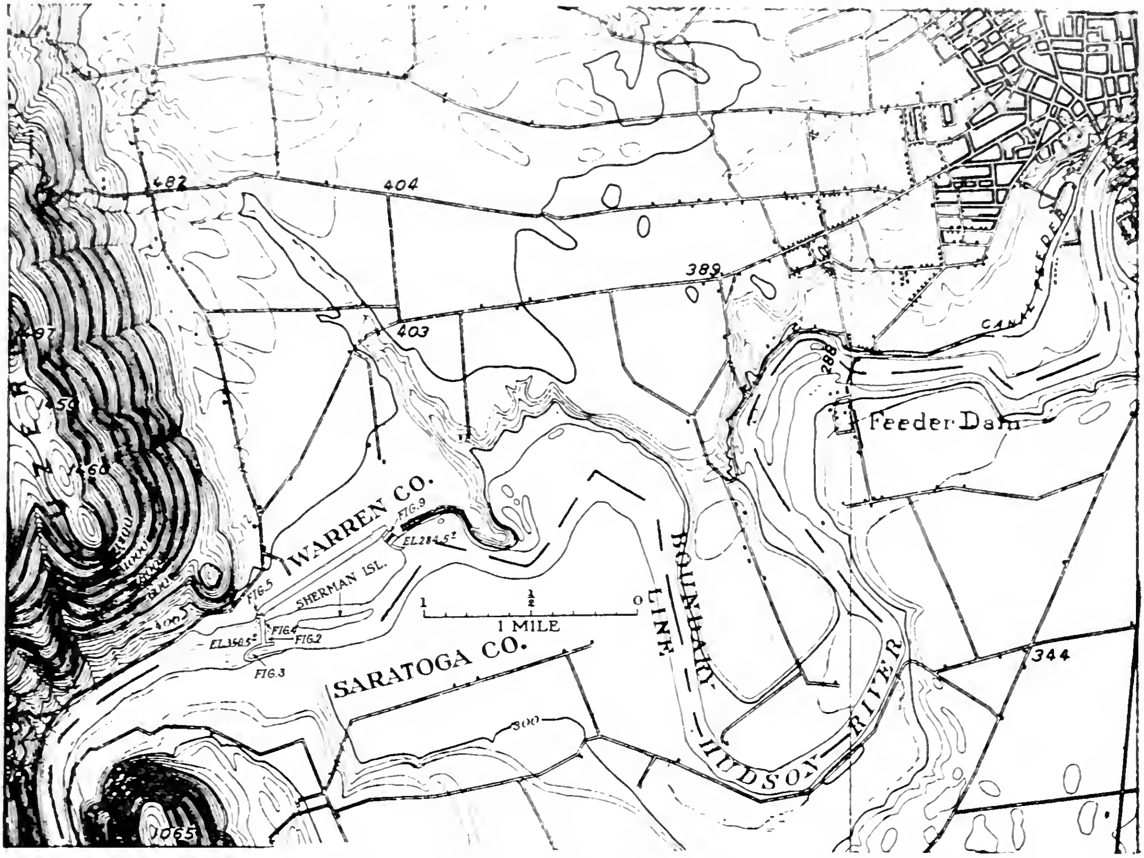


Fig. 1. Location of the Sherman Island Hydro-electric Plant on the Hudson River, four miles west of Glens Falls, N. Y. The numbered arrows indicate the locations where the corresponding photographs were taken. (Illustration based on a U. S. Geographical Survey map)

Head Gates

The headgate structure is a buttressed-type dam for 35 ft. head bedded in the solid granite mountain shoulder. The buttresses are 40 ft. from front to back at the bottom and 10 ft. from face to face. The eight openings to the power canal are controlled by eight reinforced concrete gates 22 ft. high, 10 ft. wide, and 18 in. thick. These gates are in three sections with a 14-in. opening between the upper two for filling the canal. Each section is protected at the corners by angle iron and each complete gate weighs about 20 tons.

The concrete structure is topped by a steel hoist runway 122 ft. long on which is mounted a 25-ton motor-operated hoist for handling the gates. A sluice with hand-operated gate provides for the passage of logs to mills downstream. A small house protects the water level transmitting instruments which are over the float well.

Fig. 5, which is a photograph taken overlooking the head gates, shows the upstream side of the arches of the main dam, and part of the weir may be seen at the far end of the dam.

Power Canal

The river bed has a drop of about 19 ft. from the dam to the head of the Barge Canal feeder pool, a distance of over two-thirds of a mile. This additional drop determined the location of the power house and necessitated the construction of 3571 ft. of canal in the sand and gravel north bank of the river.

The canal bottom is 32 ft. wide at elevation 324 ft. and the top edges of the concrete sides are 128 ft. apart at 356 ft. elevation. The bottom and about 40 ft. up the sides are of 6-in. reinforced concrete while the upper 18 ft. of sides are 9-in. thick.

The down-stream end is enlarged to form a forebay with the lining sealed to the forebay dam to prevent leakage and undercutting. Tests show that the canal leakage is negligible.

Forebay Dam

The forebay dam is a buttressed structure over 300 ft. long built on a slab in the sand and gravel river bank. A sheet-steel pile cutoff near the forebay side prevents under seepage. The buttresses are 3.5 ft. thick, 10 ft. face to face. Fifteen inter-buttress spaces are closed by Broome Caterpillar type gates which are handled by a like number of Maine Electric Hoists housed in a brick and steel superstructure. The hoists are operated by 15-h.p. motors having local individual control and also remote control in groups of three from the power-house. Hand-operated gates open to a log and ice sluice of timber construction leading to the river east of the power house.

Water passes from the forebay under a skimmer apron wall through trash racks and gates to the penstocks. Over the trash racks is a concrete trash trough which can be flushed to the log chute. The construction of the forebay dam and connected structures is shown in cross-section in Fig. 6.

Penstocks

The penstocks are of novel construction being of reinforced concrete with walls 2 ft. thick enclosing 15 passages 10 ft. by 10 ft. 8 in. aggregating over 1500 sq. ft. The penstocks are cast in groups of three, each group leading to a single turbine scroll casing. The penstock length of 240 ft. is divided into transverse sections so that there are 20 perforated blocks in the penstock structure. The sections nearest the power house are thickened on the upper side to form an above-ground deck for the outdoor transformer and switching station. The penstocks drop 35 ft. from the forebay dam to the turbine scrolls.

Power Station

In Figs. 6 and 7 are shown the elevation and plan of the power station. The substructure of the power station, 80 ft. by 220 ft., consists of a huge concrete block 50 ft. deep containing the five moulded-in-concrete turbine scroll casings and draft tubes. The superstructure is of steel and brick construction and houses the generators, low-tension switch gear, operating board, etc. The bearing material is entirely of sand confined in ten rectangular columns by interlocking steel piling. Settlement stopped during the process of the construction work and there has been no signs of its recurring.

The superstructure carries a 50-ton Shaw crane which serves the main floor as well as a standard-gauge track that enters the west end of the station. Ventilation is provided by a double row of monitor sash 180 ft. long in the roof. This is motor operated with remote control from the floor. A two-story extension along the head gate side is provided for housing the 6600-volt bus structure and miscellaneous auxiliary equipment on the first floor; and offices, main switchboard control room, and circuit breaker gallery on the second floor. The control room projects into the station proper giving a good view of the main floor. Stairways to the main floor are provided at both ends of this projection.

Waterwheels and Governors

The number and size of units to be installed are generally determined by the hydraulic conditions. However, the character of the load, as well as the maximum and minimum stream flow, and the possibilities of future storage developments have to be taken into account to insure operation at the highest efficiency. Only by the careful weighing of all the factors is it possible to utilize to best advantage the water available. After a study of all these factors for this particular plant it was decided to supply four units initially with five units for the complete development.

These waterwheel units are each rated at 10,000 h.p. when operating at a speed of 150 r.p.m. and under a net effective head of 66 ft. The turbine is set with a concrete casing, and a cast-iron speed ring and pit liner which serves not only as a support for the turbine itself but to transfer the load of the generator to the power house foundation.

The design of the draft tubes is of the Moody spreading type which has been shown by recent tests to have a very high efficiency.

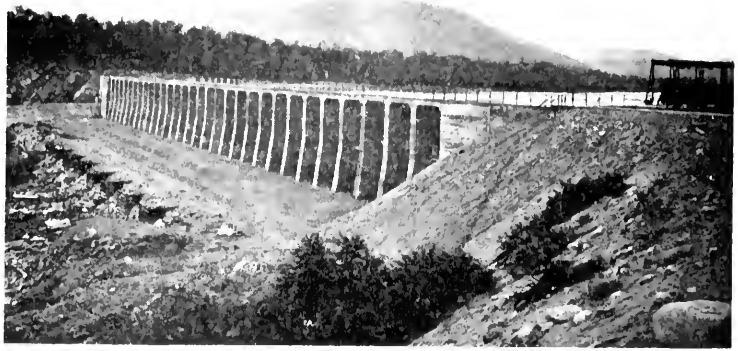


Fig. 2. Main Dam from Bank of Power Canal. The dam is 551 ft. long and 70 ft. high, and is built on gravel and boulders

Fig. 3. Spillway from South End of Main Dam. Its great length 864 ft prevents floodwater overtopping the dam

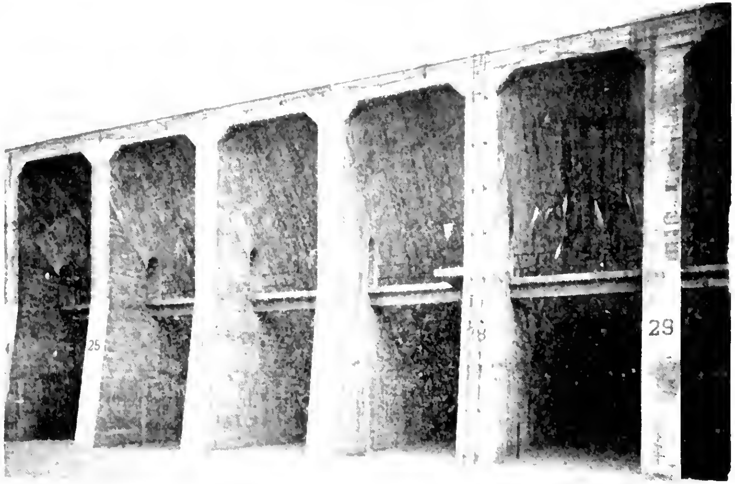


Fig. 4. A Detail of the Main Dam. A depth of 20 ft. of sand on the slab reduces the apparent height very materially

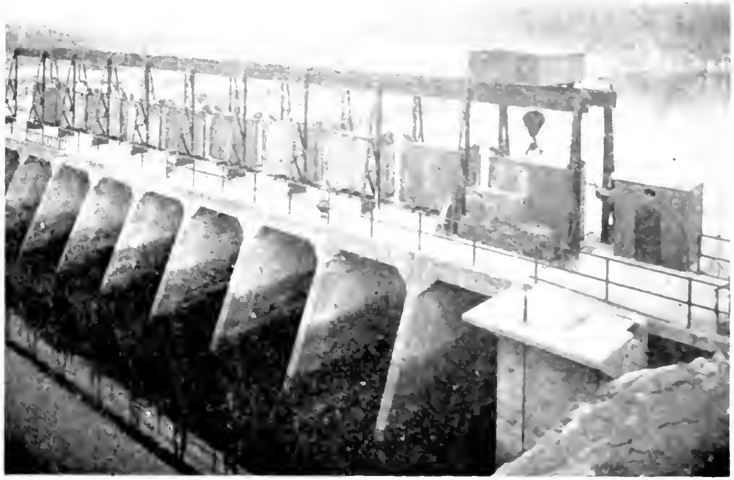


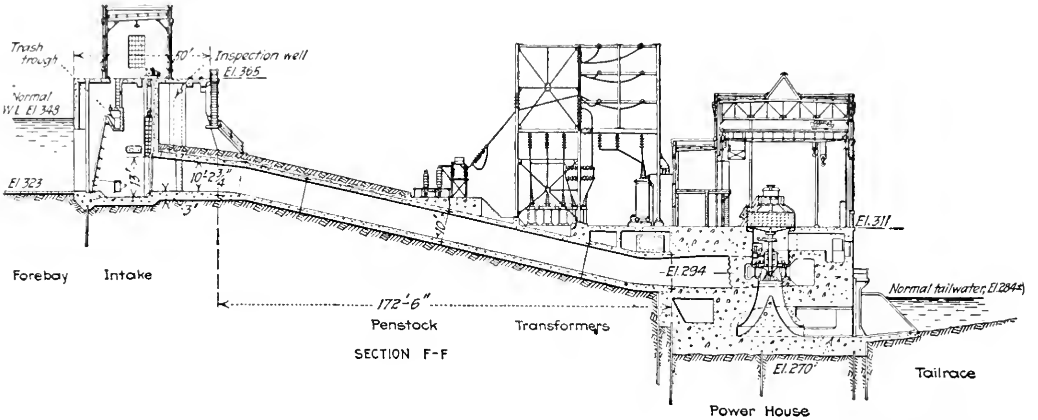
Fig. 5. Headgates and Gate Hoist Overlooking the Pond. A portion of the dam and spillway may be seen through the hoist runway

Each waterwheel unit is controlled by a governor which is oil operated and belt driven from the main shaft. These are of the I. P. Morris double-floating lever type, such as has been installed at a number of recent plants in this country.

The governor pumps and accumulators are mounted on the generator floor near the downstream wall. The pumps are each driven by a 30-h.p. induction motor; three such units are supplied, one being a spare for the present.

Generators and Exciters

The present installation consists of four vertical-type generators which are three-phase 60-cycle machines and have a continuous rating of 9000 kv-a. (7200 kw. at 0.8 p.f.), 150 r.p.m., 6600 volts, and are furnished with direct-connected exciters. Fig. 8 shows the generators and their exciters.



Courtesy of Engineering News Record

Fig. 6. Cross-sectional Elevation through Forebay Dam, Penstocks, Outdoor Station, and Power House

The generators are designed with an inherent reactance of approximately 27 per cent to limit the current of each machine under instantaneous short-circuit conditions to 3½ or 4 times full-load current.

The armature winding consists of form-wound coils with both ends of the phase windings brought out so that current transformers can be inserted inside the Y connection for differential protection of the generators. A station neutral bus is provided to which the neutral of each generator can be connected through a solenoid-operated oil circuit breaker. These switches are remote controlled from the benchboard.

Temperature coils are also installed in the armature windings and connected to the indicating temperature meters on the benchboard. The armature frame is made up of two sections having a total weight of approximately 67,000 lb., the outside diameter of the machines being 18 ft. 2 in. The total height of the unit from the face of the coupling to the upper end of the shaft is approximately 19 ft. 9½ in.

The rotor is made up of two sections, each consisting of a solid cast-steel wheel mounted on the shaft, one above the other into which the field poles are dovetailed. The total weight of the rotor including the shaft is 92,500 lb. and it has a flywheel effect (WR^2) of approximately 2,900,000 lb.-ft. It is designed to withstand a maximum runaway speed of twice normal with an ample margin of safety.

A heavy bracket-arm type of construction as shown in Fig. 8 supports the thrust bearings, which are of the General Electric spring plate type, mounted on the thrust deck, formed by the bracket arms, and between the generator and exciter. These bearings each carry a total load of approximately 200,000 lb. including all rotating parts of the generator, waterwheel, and water thrust. Cooling coils are provided in the thrust bearing housings supplied with water from the station header that is tapped from the penstocks as mentioned later. Two guide bearings are also supplied with each machine, one located just below the thrust bearing and one below the rotor.

The oiling system of these generators is of the unit type, that is, each machine has an independent system consisting of individual Richardson-Phenix filter and Brown & Sharpe gear pump for circulating the oil to the thrust and guide bearings. This system makes a considerable saving in cost of station oil piping. The pumps are gear driven from the main shaft and with the filters are located in the generator pit.

Six brakes are provided for shutting down the unit. These are of the plunger type and are air operated from the station air system supplied by a motor-driven compressor. These brakes also serve as combined jacks for lifting the rotating elements to allow for dismantling the machine when necessary. When applied as jacks, oil is used from a special hand-operated high-pressure oil pump supplied for this purpose.

Generator-field rheostats are omitted and voltage control is obtained through the exciter field rheostats, thus eliminating the losses of the generator-field rheostats.

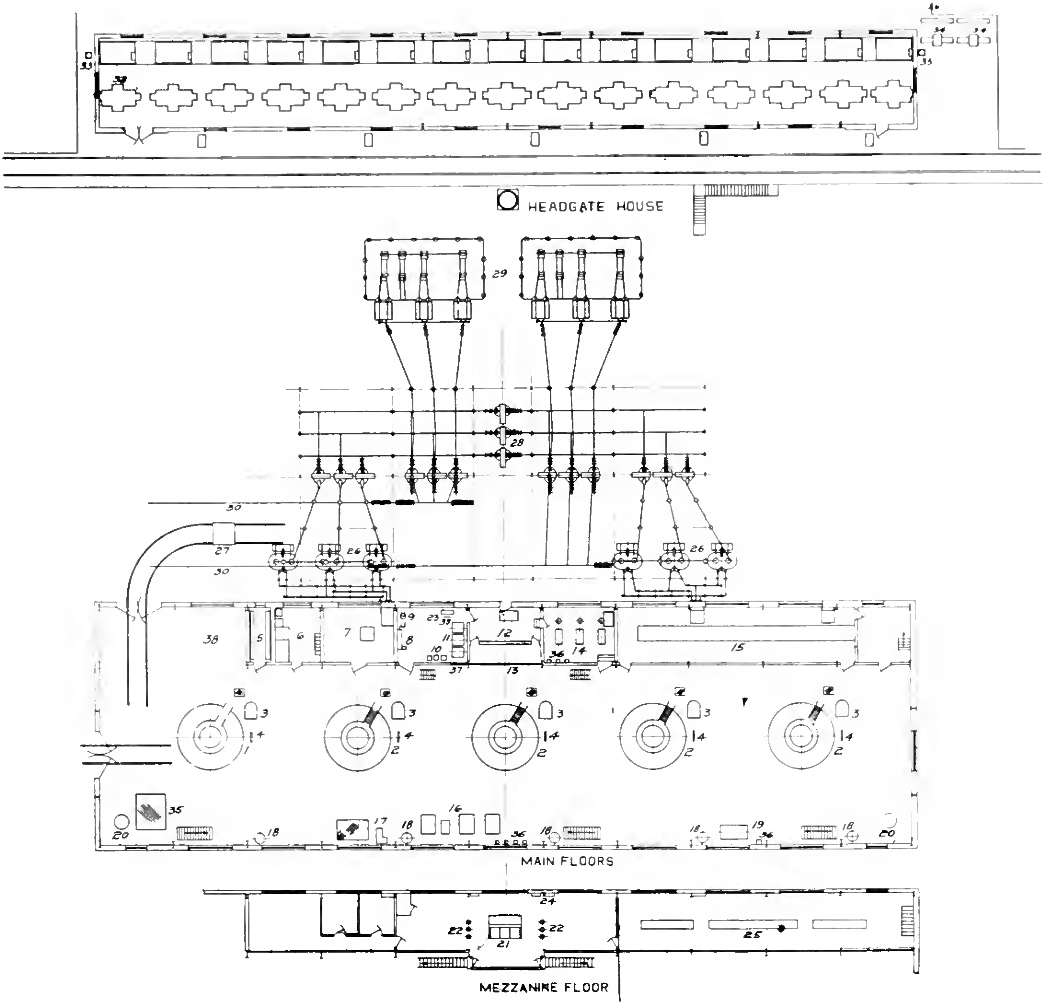


Fig. 7. Plan of the Headgate House, Outdoor Station, and Power House

1. Generator (Future)
2. Generators
3. Governor
4. Field switch panel
5. Storage battery room
6. Toilet room
7. Store room
8. Air compressor
9. Series lighting transformer
10. Lighting transformers
11. Station service transformers
12. Conduit room
13. Station service switchboard
14. Transformer oil cooling equipment
15. 6600-v. bus compartments
16. Governor oil pumps
17. Air compressor
18. Accumulators
19. Motor-driven exciter
20. Heater cowls
21. Bench board
22. Voltage regulators
23. Battery charging set
24. Water-level recorders
25. 6600-v. oil circuit breakers
26. Main transformers
27. Transformer transfer car
28. High-tension oil circuit breakers
29. Lightning arresters
30. Transmission lines
31. Disconnecting switches
32. Gate hoists
33. Trash trough gates
34. Ice and log chute gates
35. Transformer pit
36. Starting compensators
37. Lighting panel
38. Machine shop
39. Battery panel

Air for ventilation of the generators is taken into the generator pits, from over the tailrace, and from there is drawn up through the machine by the rotor fans and discharged into the generator room through ducts in the stator.

Each direct connected exciter is rated 114 kw., 150 r.p.m., 250 volts. These exciters are shunt wound and are mounted directly above the thrust bearing. They are not operated in parallel and each is controlled by an individual voltage regulator.

A spare exciter of the same capacity has been provided, direct connected to a 1200-r.p.m. squirrel-cage induction motor operating off the 550-volt bus. By means of a transfer bus this exciter can be thrown on any field through the double-throw generator-field switches which are mounted on separate panels on the floor near the main generator thus making the exciter main leads as short as possible.

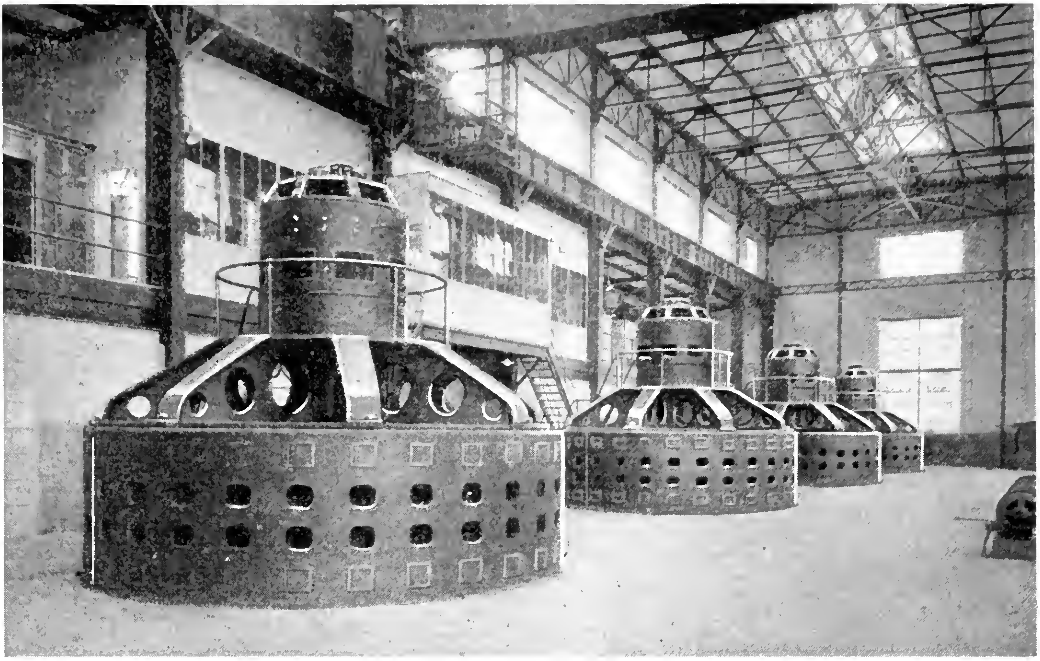


Fig. 8. Interior of Power House Showing Four 9000-kv-a. 150-r.p.m. 6600-volt Generators with Direct-connected Exciters. The projecting part of the gallery shows the location of the operating room

Main Transformers

The voltage is to be stepped up from 6600 to 114,500 volts for transmission. The transformers will be star connected on the high-tension side with dead grounded neutral but for a few months will be operated at 66,000 volts delta connected. There are seven units of outdoor construction rated 7500 kv-a., 6600-66,000/114,500Y volts, one unit being a spare. After a careful study of various transformer arrangements it was decided to use two banks, each consisting of three single-phase units with one as a spare, as being the most economical layout and advantageous arrangement from an operating standpoint.

The transformers are of the core-type construction with concentric-disc helical windings. Two $2\frac{1}{2}$ per cent full capacity taps above and below normal voltage are provided in the high-tension winding. Conservators are a feature of these units as shown in Figs. 9 and 13, which also show the spare transformer.

The tanks are of reinforced boiler plate construction and are equipped with alarm type thermometers. Each transformer is furnished with trucks. A transfer truck of standard gauge is provided so that the transformers can be run into the generator room under the main station crane for dismantling if necessary.

Instead of being of the usual water-cooled type, these transformers are of the forced oil type, the oil being circulated through an external cooling system. This system was used as trouble had been encountered in other locations above this plant due to pitting and corroding of water cooling coils from impurities in the river water. For each transformer bank there is supplied a motor-driven centrifugal pump for circulating the oil and a Griscom Russell multi-whirl type oil cooler, with a third complete unit provided as a spare. The pumps and cooler are capable of handling 198 gal. of oil per minute, and are located in a separate room under the main operating gallery near the center of the building.

The use of one cooling equipment consisting of cooler and pump for each bank of three transformers made it necessary that in the design of this piping system an equal distribution of circulating oil should be assured in the three transformers. To meet this requirement an attempt was made to equalize the velocity of the oil at the inlets of the three transformers. This was accomplished by increasing the size of the pipe line between the first, second, and third transformers. Equalizing of flow was also obtained by means of a regulating globe valve in the inlet line to each transformer. To prevent leakage of water into the oil in the event of a leak in the oil cooler, it is essential that the oil pressure in the cooler is kept at a higher value than the water. Pressure gauges were therefore located on the ingoing water line to the coolers, and on the outgoing oil lines. Thermometer wells were located in the ingoing and outgoing oil and water lines to the coolers in order to enable the operator to check up the efficiency of the cooler, and to be assured that the system was operating satisfactorily.

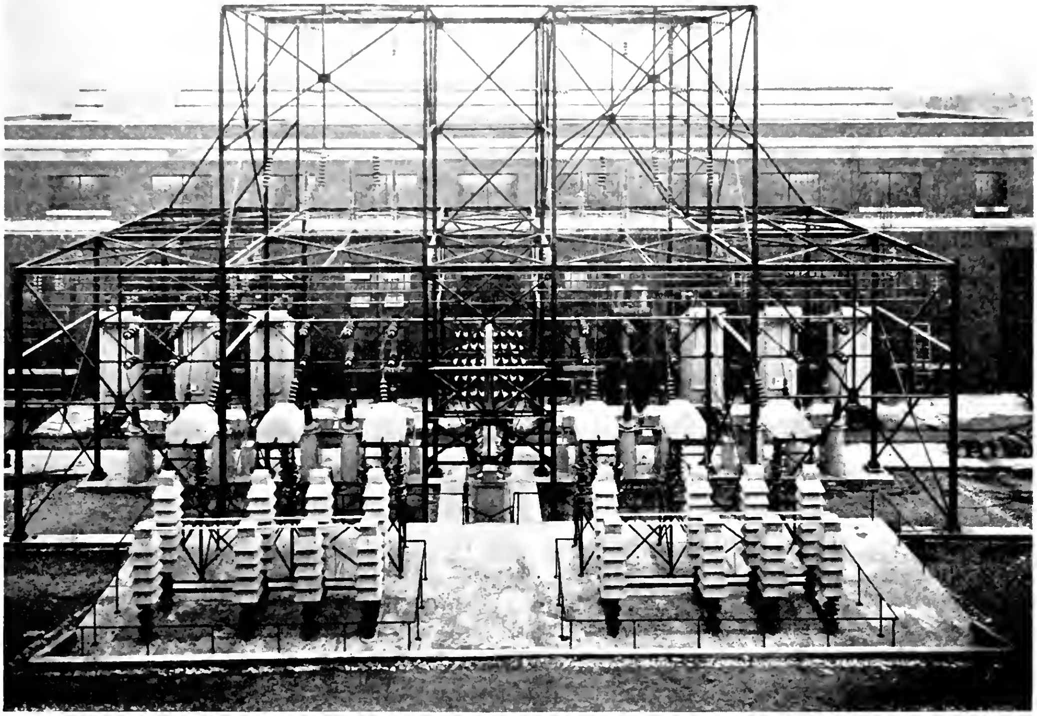


Fig. 9. View of the Outdoor Transformer and Switching Station from Forebay Dam. The transmission lines lead off to the right. The concrete deck is a part of the penstock formation

The three cooling equipments have been piped up to a combination of headers so that the spare cooler can be used with either bank of transformers or in the event of only one transformer bank operating any one of the cooling equipments can be used. An oil storage tank is provided in the space beneath the slab of the outdoor substation and valves inserted in pipe lines so that the oil from any transformer can be drained to this tank if desired. A connection from this tank is also taken into the pump room so that oil can be pumped from this tank through the filter press into the oil cooling system. The filter press is also connected to a header in the pump room in order that oil from either equipment can be filtered. These headers were tapped off the hot and cold oil lines so that the filter can operate in parallel with either cooler. Cooling water for the multi-whirl coolers is supplied from a 6-in. header which taps penstocks No. 2, 3, and 4. Shut-off valves are provided in each penstock so that a constant supply of cooling water is assured. A closed 10-in. drain pipe leads from the pump room to the tailrace for discharge of the cooling water.

Switching Equipment

The electrical control of the entire station, including the main generators, outdoor equipment and headgate motors, is centralized in the control gallery which is located on the balcony in the central part of the station. The main control switchboard is of the bench-board type and of natural black slate. There are three sections, the two end sections each containing the control of two generators and one outgoing high-tension line. The central section contains the control of one generator, station auxiliary equipment, and space for a future outgoing line. Figs. 11 and 12 show general views of this control board.

The bench section contains a mimic bus showing the main connections of the station and the control switches for the remote control of oil circuit breakers and field switches which are motor or solenoid operated, synchronizing and potential receptacles, etc. The indicating instruments are of the horizontal edgewise type and are mounted on the vertical section above the bench.

On the sub-bases are mounted the control equipments for the temperature indicators of the generators and transformers, and the rheostat controls for the exciter field and regulator adjusting rheostats.

In the rear of the bench section is a vertical section, the interspace being enclosed by grill work with a door in each end. On these rear vertical panels are mounted the recording and curve drawing meters, relay equipment, and testing or calibrating terminals.

At each end of the main board are mounted the voltage regulators on individual pedestals. An individual automatic voltage regulator is supplied for each direct-connected exciter and another regulator of different type for the spare motor-driven exciter set. In the rear of the control gallery is mounted a vertical panel for controlling the storage battery and its charging set.

On the rear wall there is mounted a small panel containing control switches and signal lights for the unit operation of the three head gate motors for each main unit in emergencies. This control is connected in parallel with that at the head gate house, where each motor is individually controlled by push buttons operating contactors. An individual light on this panel indicates when each gate is in the full open or closed position.

Fig. 10 is a one-line diagram showing the main connections of the entire station.

The 6600-volt oil circuit breakers for each generator, transformer, station service, and bus tie are of the 15,000-volt motor operated H type equipped with stuffing boxes and separating chambers. The generator circuits are non-automatic except for differential protection against internal failure, the station service circuits being automatic with time-limit overload relays. The main transformers are protected by differential relays.

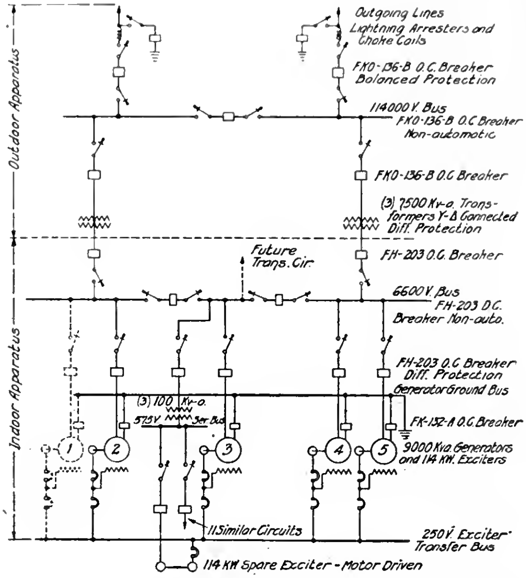


Fig. 10. One-line Diagram of the Power Station and Outdoor Station Circuits

The five high-tension oil circuit breakers are of the high interrupting capacity, tank type, equipped with explosion chambers. One is installed between each transformer and the high-tension bus, one in each outgoing line, and one serves as a bus-tie switch as will be seen from Fig. 10.

The two outgoing lines are each rated 45,000 kw. capacity and are protected by balanced reverse power relays with overload relays.

Fig. 11. Front View of Main Control Switchboard

Fig. 12. Back View of Main Control Switchboard

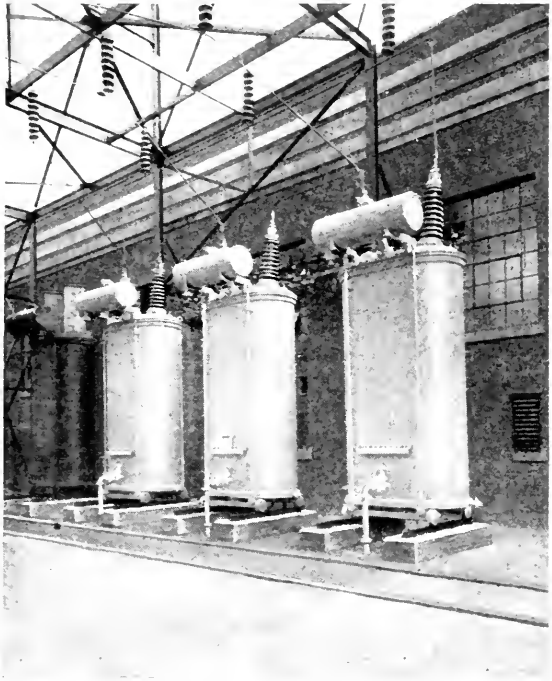


Fig. 13. One Bank of 7500-kv-a. 6600-66000 114500-volt Transformers Equipped with Conservators. These units are truck mounted and a transfer car serves to bring them under the power station crane

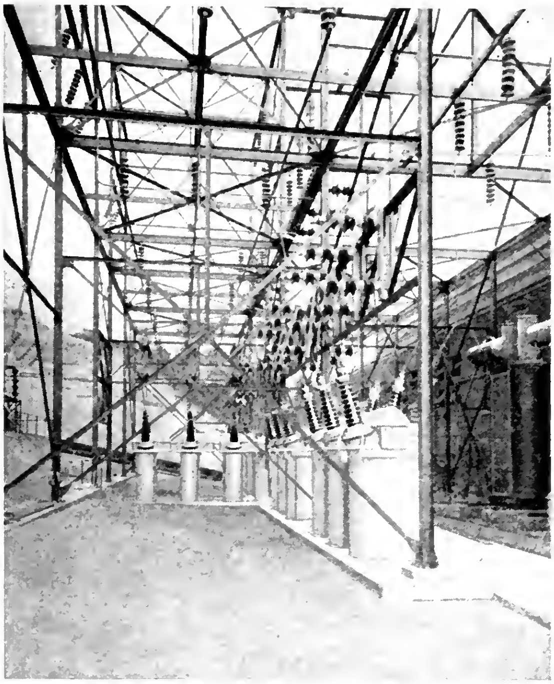


Fig. 14. High-tension Circuit Breakers and Disconnecting Switches. The nature of the forebay and power house site is shown by the bank in the background

Low-tension Oil Circuit Breaker and Bus Structure

The bus and oil circuit breaker cell structures are in separate compartments to the left of the control gallery. The bus cells are on the generator floor level and the oil circuit breaker cells on the gallery level.

The bus structure was constructed of hard-burned pressed brick, light tan in color. Concrete slabs were used for all horizontal sections in the bus structure and soapstone slabs in the circuit breaker structure.

In the design of the bus structure the main buses were located in compartments in the front of the structure so that they are accessible for inspection and cleaning, and the connections to the oil circuit breaker were taken off at the back of the compartments.

All conduits for control and instrument transformer leads are run concealed in the gallery floor from the benchboard to the oil circuit breakers and instrument transformer compartments. In the compartments, however, they are necessarily run in the open and are located close to the front of the compartments clear of all live parts and accessible for installing the cables. At the oil circuit breakers, conduits are run exposed up the back of the rear wall.

Strips of 1 by 1/8-in. copper straps are run throughout the length of the bus structure and circuit breaker cells for the grounding of bases of disconnecting switches, the casings of current and potential transformers and operating mechanisms of the oil circuit breakers. The bases of bus supports however were not grounded. The secondary windings of both the current and potential transformers were grounded at the transformers only, and not at the switchboard, and in every case a ground wire was carried to the switchboard with the other conductors in the circuit.

For groups of instrument transformers consisting of two current transformers and two potential transformers, two independent ground wires were taken to the switchboard for each equipment. This was necessary in order that the voltage drop in a common wire from two current transformers would not introduce an error in the potential transformer circuit. Where three current transformers were used the use of separate ground wires was not necessary.

The arrangement of buses one above the other and the mounting of the supports on the horizontal slabs of compartments eliminated all cantilever forces in supports, due to magnetic stresses at time of short circuit. Thus the moderate duty bus support was satisfactory for this installation.

The low-tension oil circuit breakers are of the improved design provided with gravel chambers and gas vents. These vents are all piped to a 3-in. header extending the full length of the row of oil circuit breakers and supported from the ceiling above. The vents from the three sets of pots in each oil circuit breaker are connected to a 1-in. header in the cell and these 1-in. pipes are connected to the main header. Gases generated in the breakers at the time of opening under severe short circuits will be discharged through this header outside the building so that no danger will be encountered from gases in the switching room.

Auxiliary Equipment, Lighting, Etc.

The entire station auxiliary equipment is operated off the main generator bus, through a step-down transformer bank, rather than from an independent supply as power will always be available through the trans nission lines for starting up the plant initially or after a complete shut-down. This gives a simpler operating arrangement and is more economical than providing a small waterwheel for supplying the auxiliary power.

This station auxiliary service is supplied by three 100-kv-a. 6600–575-volt transformers, and three 15-kv-a. 575–115/230-volt transformers supply the station lighting. A 5-kw. 575-volt, 6.6-amp. series lighting transformer is also provided for the lighting of the head gates and grounds around the operators' cottages which are located along the pond above the main dam on the north bank of the river.

To insure the transformer oil being in proper condition, a 3-kv-a. oil-testing transformer equipment and an oil filter press and drying equipment of 30 gal. per min. capacity are also included in the station equipment.

The control for the 550-volt auxiliary circuits in the station, including the series lighting equipment and a machine shop, is taken from an auxiliary switchboard located directly under the operating gallery on the generator floor level. This board consists of six double-circuit panels equipped with automatic oil circuit breakers.

Operating current for the solenoid and motor operated oil circuit breakers, rheostats, emergency lighting, etc., is supplied by a 60-cell Exide storage battery. A 4¾-kw. induction motor-driven charging set is supplied for charging and is operated continuously with the battery floating. The emergency lighting is thrown from the alternating-current circuit to the battery circuit by an automatic throw-over switch on the battery control panel.

Ample light is provided by day from numerous large windows on three sides and monitors in the roof of the generator room. These windows and monitors are also arranged to provide for natural ventilation of the building.

The three lighting transformers supply power for lighting the generator station, outdoor station, and head gate house. The general illumination of the station is furnished by 200-watt units mounted in angle reflectors on each of the building columns 21 ft. from the floor. These lamps are controlled by four circuits from the main panel box and are connected so that alternate lamps are on each circuit to allow controlling the quantity of light to suit the requirements. An additional row of 200-watt units with reflectors are installed in the roof trusses, alternate lamps being connected on the emergency lighting system to provide general illumination around the machines in case of trouble on the alternating-current system. The control room is lighted by six 200-watt units with improved glass-steel reflectors, which type has been designed for locations where semi-indirect lighting is desired but where no reflecting surfaces are available. The bus and circuit breaker rooms and other similar rooms are lighted by 75-watt units. The lighting of the outdoor yard is by floodlights, two 500-watt units being located on poles at each side of the yard.

A complete water-level indicating equipment is installed showing the water levels at the canal head gates, the gate house, and the tailrace. These are remote operated and the meters are located at one side of the switchboard operating gallery.

FEATURES IN STATION DESIGN

The transformers, high-tension oil circuit breakers, and lightning arresters are located in an outdoor station adjacent to the generating station on a concrete slab over the penstocks on the northeast side of the building, Fig. 9. The location of the outdoor equipment in this space was pertinent in the design for the following reasons:

(1) To facilitate the handling of equipment it was desirable that the outdoor station yard level be located at the same elevation as the main floor of the station so that a transfer track could be installed by means of which transformers could be taken into the station on the transfer car and the station crane used for dismantling of this equipment.

(2) The location of the substation at this point simplified the piping of the oil cooling system for transformers; and as it is desirable to have the pumping equipment for this system located in the station, where it is under observation of the floor operator, this location gave a very flexible and compact arrangement.

(3) Severe climatic conditions in this section of the country also made it desirable that the outdoor station be located as close as feasible to the generating station to assure frequent inspection and also to facilitate the operation of disconnecting switches during the winter season.

Steel Structure

In the design of this structure 8-in. H sections were used for columns in the lower tier and 6-in. H sections in the upper tier. Deck framing was made up of channels and I beams. Angles were used for bracing throughout. Light sections requiring the use of latticing were avoided inasmuch as the use of heavier rolled sections reduced shop and maintenance charges. Furthermore, this type of structure presents a smaller number of exposed sides so that painting insures a good weather resisting surface and is very easily renewed. All shop connections were riveted and the field connections bolted.

Outgoing line anchorages were designed for a load of 3000 lb. per phase and other strain connections for 2000 lb. Tensile stresses were limited to 20,000 lb. per sq. in. For the main compression members the ratio of slenderness was limited to 150, and for secondary members to 180.

High-tension Connections

In designing the high-tension connections the use of disc-type insulators in a strain position was avoided as far as possible. The main buses are made up of 2½-in. dia. standard galvanized iron pipe, and supported by strings of 8-unit Hewlett insulators spaced 25 ft. apart. This size pipe was not necessary to obtain sufficient current capacity, but was used to permit a wider spacing of supporting insulators without undue sagging of buses under an ice load of ½-in. thickness. This wide spacing of insulators made a considerable reduction in the number of insulators required and also in the amount of the steel work.

Connections from the oil circuit breakers to the buses and transformers were made with 1-in. standard iron pipe size copper tubing. The size of these connections was determined by length of span rather than current capacity. Machine cast bronze alloy connectors of the belted type were used for making connections between the several lengths of pipe.

The general direction of outgoing lines from this station was at right angles to the natural direction to conform with the arrangement of equipment in the substation, and as space was not available between the substation and gatehouse to permit the use of turning towers, it was necessary to obtain this change in direction within the substation structure itself. This was accomplished by introducing two vertical stub buses in an upper section of the tower directly over the line oil circuit breakers. This proved to be a very satisfactory arrangement and allowed the transmission lines to enter the structure in the same relative vertical positions as on the line and at the same time occupy a minimum width of structure. The two transmission lines were terminated in the upper tier of the structure in the same bay as required for the transformers on the lower tier.

Lightning Arresters and Choke Coils

The choke coils are located in the vertical stub buses and connections to lightning arresters are taken off the stub buses at points corresponding as closely as feasible to taps from the line so that the path to the lightning arrester is as direct as possible.

Two sets of disconnecting clamps are provided at the lightning arresters, one set will be used for disconnecting the arrester from the line for inspection. The second set of disconnecting clamps has been provided for grounding the transmission lines at the station, and when clamped to the line above the strings of insulators, connects the line through flexible connections to the ground bus on the arrester framework.

Disconnecting Switches

In the design of the station, the space available was limited and the width of the structure was a determining factor. Advantage was therefore taken of the improved heavy-duty built-up type post insulator which permitted the mounting of disconnecting switches with the insulators in the horizontal position. The introduction of this feature in the design resulted in a very simple arrangement of equipment and reduced the ground area to 75 per cent of that required if disconnecting switches had been mounted in the underhung position.

Oil Circuit Breakers

The spacing between columns in the outdoor structure is governed by the space required for the oil circuit breakers and transformers. It is the usual practice to space columns at oil circuit breakers sufficiently far apart to allow space at the end of the breaker for inserting an emergency handle at the solenoid for hand operation. In this design an appreciable saving was made in the length of bay by turning the solenoid operating mechanisms 90 deg. so that the emergency handle could be operated at the side of the breaker where there was already space provided for the transferring of main transformers. This feature reduced the length of the bays at the oil circuit breakers from 30 to 25 ft. with a corresponding saving in steel work.

Spacing of Conductors

Minimum spacing of 5 ft. 4 in. between live parts and 4 ft. 8 in. between live parts and ground were maintained throughout this design. The spacing in most cases, however, exceeded these values due to space requirements for the apparatus so that throughout the design very liberal spacings were obtained without increasing the size of the structure.

Grounding System

As the outdoor station was constructed on a concrete slab a good grounding medium in the immediate vicinity of the grounding apparatus was not assured. A 4/0 bare copper cable was therefore buried in concrete throughout the switch yard, and at each end of the substation cables it was run to the tailrace where copper ground plates 2 ft. square by $\frac{1}{8}$ in. thick were buried in moist earth well below the minimum tail-water level and imbedded in charcoal to assure a good connection to ground.

Casings of all apparatus and columns of steel towers were connected to this ground system. In addition to these points of grounding, ground connections were also attached to the steel piling which formed a box work about the entire station.

Separate ground circuits were run from the lightning arresters to separate ground plates near the tailrace, and in addition to these a series of iron pipes were driven into the earth to a depth of 8 to 10 ft. beyond the edge of the concrete penstocks.

Auxiliary Transformer and Battery Room

Following the general practice of locating transformers in a room isolated from the remainder of the equipment in the station, a special transformer room has been provided in which are located the station service, station lighting, series lighting, and testing transformers. The battery charging set and air compressor equipment have also been located in this room.

In addition to limiting the fire hazard, the locating of all this secondary equipment n one room, isolated from the remainder of the station, improves the appearance of the station and localizes this equipment.

In the design of the battery room the usual precautions were taken. The cells were mounted on two impregnated wood frame supports in two rows, two tiers high, along the sides of the room, and a special floor covering of acid-proof tile set in bitumastic compound was provided and drained by an acid-proof drain pipe. The walls and exposed steel work and conduits were painted with asphalt paint, and the lighting unit installed in a gas-proof fixture and controlled from a switch located outside the room close to the door opening into the battery room.

To insure proper ventilation a wooden louvre was installed in the space provided for a window.

Weatherproof covering was used on all conductors entering the battery room, and all openings in conduits were closed with an asphaltum compound.

All exposed copper was well coated'with vaseline to prevent corrosion from the acid fumes.

Power and Control Cables

The main leads from the generators to the low-tension oil circuit breakers were made up of one 1,500,000-cir. mil single-conductor rope-core varnished-cambric-insulated cable per phase, insulated for 8500 volts. In place of the usual weatherproof braid covering used on single-conductor cables carrying alternating current, a special rubber hose jacket was provided thus assuring better protection against moisture. Over this rubber jacket a tape impregnated with compound was wrapped to protect the rubber jacket from mechanical injury, and also to exclude air from the rubber, thus prolonging its life.

The low-tension transformer connections were made up of two 2,000,000-cir. mil rope-core single-conductor cables per phase, the same insulation and covering being used as on the generator cables.

All control and low-tension power cables in the station were provided with weatherproof covering while all cables leaving the building either to the outdoor substation or to the head gate house were provided with lead covering. Bare copper cables were used for the ground system throughout.

Three-inch drive-joint fiber conduits were used for the generator and transformer leads, and hot-dip galvanized-iron conduit for all low-tension power circuits and control.

TRANSMISSION LINE

The Adirondack Power & Light Corporation's two transmission lines lead from the side of the outdoor structure in a southwest direction over Palmertown Mountain running to the high-tension buses at its Spier Falls Station. This line is four miles in length and consists of one double-circuit tower line, the towers being of the square, rigid type and galvanized. The conductors are in a vertical plane spaced 9.5 ft. apart and consist of 4/0 stranded copper supported by eight insulators in suspension and nine in strain. The distance between lines at the top and bottom wires is 17 ft. and at the middle wires 20 ft. The insulators are the Locke No. 5800 10-in. cemented type. A $\frac{3}{8}$-in. steel-core copper-clad ground wire is installed and a private telephone line is strung on the main towers.

From the Spier Falls bus the lines will be connected by a 114,500-volt line to the main system of the Adirondack Power & Light Corporation and its new outdoor main distributing substation near Rotterdam just west of Schenectady.

Studies in the Projection of Light

PART VIII

PARABOLIC MIRROR AND DISK SOURCE OF LIGHT (Concluded)

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

The characteristics of a parabolic mirror and *spherical* source of light were described in our April and May issues. The treatment of the same type of mirror and a *disk* source of light was begun in the September number, continued in the November, and is concluded below with a second graphical method whereby greater accuracy can be obtained and the analysis for beam characteristic may be made at any desired distance between the searchlight and the plane of analysis. The method is moreover perfectly general in its applicability, and by obvious changes the solution might be applied to light sources of square or rectangular form. With this graphical method as a standard, the usefulness of certain equations previously developed is shown to be limited in some directions. The final paragraphs deal with the selection of the best testing distances, which is one of the main goals of these studies. In a forthcoming issue the methods here developed will be applied to concrete examples of searchlight design, and the data of the high-intensity arc will be used exclusively.—Editor.

Second Graphical Method of Obtaining the Beam Characteristic

Elliptical Elemental Image

In a previous section,* the beam from a double-disk source was built up for a mirror having a generating angle of 120 deg.; but in the introduction of that description, note was made of the conditions under which the method of circular elemental images was lacking in accuracy. It is now proposed to go into the details of a similar method based on elliptical elemental images. This method, while not so simple as the previous one, is perfectly general in its application and may be used to determine beam intensities from odd shaped sources, from defective mirrors, or to obtain the distribution of light in the beam at short range.

The maximum dimension of the elemental image from a section of a mirror, at an angle a from the axis, is

$$C_{max.}=\frac{57.28r}{F}\,(1+\cos a)\text{ deg.}\quad(114)$$

The minor axis is equal to the major axis foreshortened by the angle a, or

$$C_{min.}=\frac{57.28r}{F}\,(1+\cos a)\cos a\text{ deg.}\quad(115)$$

and, as already derived, the average diameter of the elliptical beam is

$$C_{ave.}=\frac{57.28r}{F}\,(1+\cos a)\sqrt{\cos a}\text{ deg.}\quad(113)$$

These three diameters, maximum, minimum, and the average that gives a circle of equal area, are plotted in Fig. 72. The average falls to zero at 90 deg. for although the image has considerable length, the width is zero; that is, it is the image of a line of zero area. The maximum corresponds exactly to the diameter of the image from a spherical source. The curves are for the particular case of $r=0.01F$ but the application to any other diameter of source is readily made by multiplying by the proper factor, as the beam width is directly proportional to the relation between r and F.

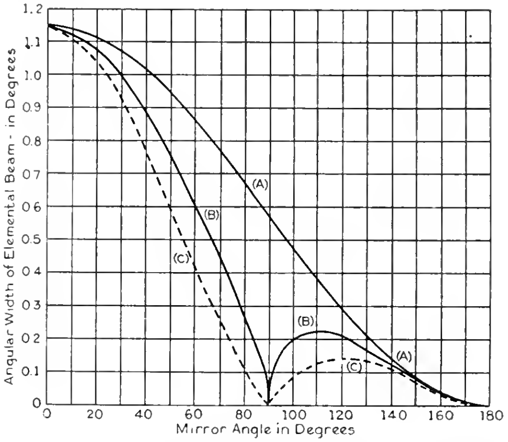


Fig. 72. The angular axial dimensions of the elemental beam images are plotted for (*A*) the major axis, (*C*) the minor axis, and (*B*) the diameter of the circle of equivalent area. The ordinates are for the particular case where $r=0.01F$

Taking an elemental image in its true elliptical form, the beam from a given mirror zone is derived graphically as illustrated in Fig. 74. The angle a is taken as 55 deg. so this ellipse represents the average from a mirror zone centering about 55 deg. The width of the zone is largely a matter of choice, but in this region of the mirror a total width of 10 deg. is not too great for reasonable accuracy. It is assumed that the beam is being investigated at ranges sufficiently great that the distance between the axis of the beam (and mirror) and the axis of the elemental beam may be neglected.

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* G. E. Review, Nov., 1923, p. 785.

The half ellipse in Fig. 74 was computed from equations (114) and (115), and the height of the zonal image was computed by equation (79) from the plane area of the mirror zones. The assumption is made that the brilliancy of the source and the coefficient of the mirror are both unity, and the immediately following figures are computed uniformly on this basis.

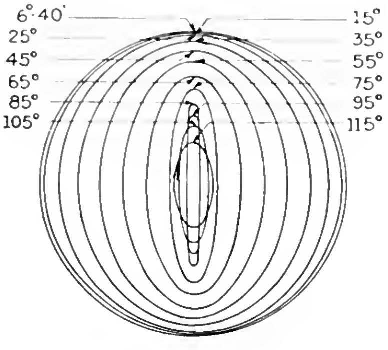

Fig. 73. The elemental images are here drawn to scale, and by their changing size and ellipticity they illustrate the relation between mirror angle and the form of the elemental parts of the beam

The multitude of elemental elliptical images from a complete mirror zone overlap in the center to give a zonal image of full intensity over a circle of a diameter equal to the minor axis of the ellipse. This formation was illustrated in Fig. 68 and the central circle there corresponds to the flat crest of the zonal image of Fig. 74. The outer diameter of the zonal image is fixed by the major axis. An intermediate point is found by noting what part of a concentric circle is included in the ellipse and making the image intensity in this proportion at the same radius. In Fig. 74 the long axis of the ellipse is taken as the zero line and radial lines are drawn at 22 deg. 30 min., 45 deg., and 67 deg. 30 min., so that these lines mark out arcs of 25, 50, and 75 per cent of the 90 deg. in the quadrant. Continuing the circles from the intersection of the radials with the ellipse until they reach the base of the zonal image, the perpendicular can then be erected to the proper proportional height to give points of 25, 50, and 75 per cent intensity of the zonal maximum.

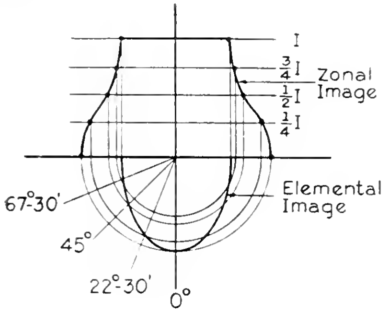

Fig. 74. The half ellipse below the horizontal axis is the elemental image from the 55-deg. point on the mirror, and the curve above the axis is the zonal image found by adding all the elemental images in the complete zone

This method may fairly be called exact, and providing the drawing is done carefully the results will have a degree of correctness that can hardly be hoped for in photometric measurements. The results of the graphical method using elliptical images is therefore regarded in the following pages as being the standard of accuracy.

In Fig. 75, a beam from a 120-deg. mirror is built up of such zonal images and the beams from a 90-deg. and a 60-deg. mirror are indicated by dotted lines. The beams are direct summations of the zonal beams with one minor exception. The width of the crest of the 60-deg. beam is determined by the 60-deg. position and not by the 55-deg. position in the middle of the zone. The crest is therefore slightly narrower than the narrow part of the 50- to 60-deg. zonal image.

If the mirror contains a 90-deg. zone, the beam must come to a point and the narrow crest indicated by the narrowest zonal width must be eliminated.

This illustration will be used later in making a comparison of the several methods for deriving the beam characteristics.

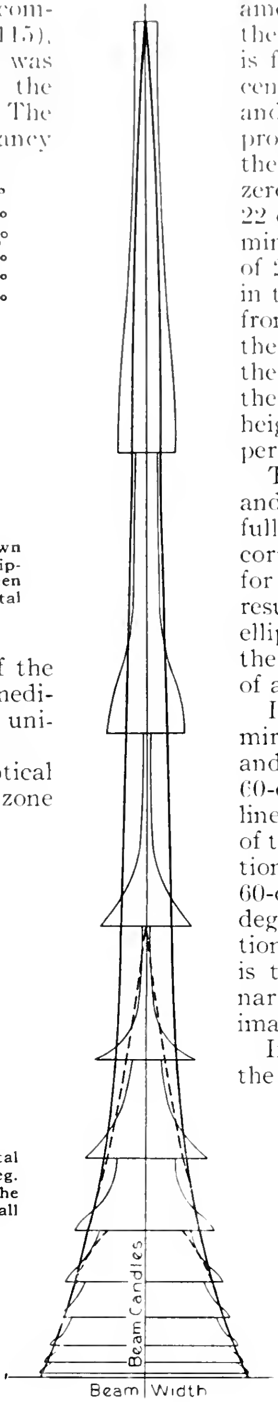

Fig. 75. The summation of all the zonal images gives the curve, shown by the solid line, for a 120-deg. mirror and a double-disk source of radius one-hundredth the focal length. The same mirror stopped down to 90 deg. and 60 deg. gives the beams shown by the dotted curves

A Curve Method of Deriving the Beam Characteristic

There is another way of using the data of equations (113), (114), and (115) that yields quick results, but as several items are left to the skill of the computer there is too much "rule of thumb" for it to be entirely reliable. In Fig. 76, the total plane area of a mirror of unity focal length is plotted for angles up to 120 deg. In Fig. 77, curve *A* is obtained by combining the elemental beam widths as plotted in curve *A*, Fig. 72, with the curve of mirror areas. Thus at mirror angle 60 deg., the maximum angular total width from Fig. 72 is 0.86 deg. (25.8 min. radius) and the mirror area or beam intensity is 4.2 according to Fig. 76. These data plot as shown by the circle on curve *A*, Fig. 77. Similarly, curve *B* is derived from the curve of average width in Fig. 72, and curve *C* is derived from the curve of minimum width, and this curve determines the width of the crest.

If we use only the curve for the average diameter of the zonal image, the summation of curve *B* will give a beam formation identical to that found by adding the zonal images in Fig. 70. The curve so obtained is in fair agreement with the curve from the elliptical images up to mirror angles of 70 or 80 deg.; but when the mirror is 90 deg. or over, the upper part is too square across the top and the sides of the upper part of the curve are too nearly vertical. This can be in part corrected by taking into consideration the long and short axes of the elemental ellipses, but before the curves for maximum and minimum width can be used certain features must be investigated a little further.

Curve *B* in Fig. 77 which corresponds to equation (113) shows a maximum width between 100 and 120 deg. By differentiating (113), a maximum is found for an angle a such that

$$\cos a = -0.33333$$

which indicates a maximum image width at

$$a = 109 \text{ deg. } 28 \text{ min.}$$

This angle can now be taken as marking out separate sections of the mirror which must be treated independently. There are thus three sections to a mirror extending beyond 109 deg. 28 min. These sections are 0 deg. to 90 deg. then 109 deg. 28 min. back to 90 deg. and from 109 deg. 28 min. on to the limiting mirror angle. The inversion of angles in the second section was made on account of the beam from the 90-deg. zone furnishing the point. The three inner ellipses of Fig. 73 illustrate how the 90-deg. to 100-deg. zone furnished both the extreme edge light and the narrow beams that make up the central short peak of the total beam. The points of the first two beams thus join at 90 deg. on the curves as plotted in Fig. 77, and the bases of sections two and three join at the intensity level of the 109-deg. zone.

Consider first the 0- to 90-deg. section. The beam characteristic curve must conform in general to the curve of average widths, and come tangent to the curve of minimum widths at the upper part of the beams. In Fig. 77, the dotted curve *E* is plotted from the curve obtained with elliptical images and it is seen that this curve agrees with the foregoing condition.

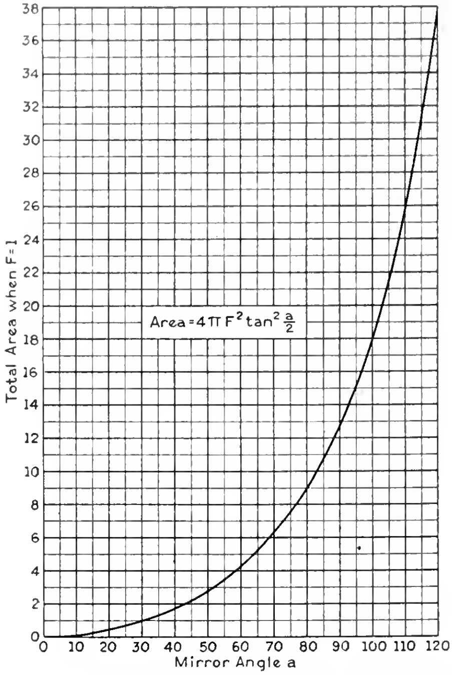

Fig. 76. The area of a mirror of unity focal length projected on the focal plane is given by this curve. The relatively great importance of the outer zones is illustrated by the rapid progressive rise of the curve

The curve for a 60-deg. mirror is also derived in the same way and shows that a curve drawn tangent to the flat crest and also tangent to the average curve will satisfy the points taken from the accurately determined curve of Fig. 75. The question now is how to draw this doubly tangent curve without previously knowing its point of tangency. This is one feature where a "rule of thumb" must be used.

The second section of the mirror gives a beam of a maximum radius of 17 min. as determined by curve *A* at the 90-deg. level. This same zone of the mirror also furnishes the beam of minimum spread for here the image is a line whose length is greater than any of the images from higher angles. (See Fig. 73.) Hence curve A has its maximum width at 90 deg. and curve C has its minimum width at the same angle. The dotted curve F which represents the beam from this section is tangent to the horizontal line at the 109-deg. level at a point determined by the A curve at the 90-deg. level, doubly tangent to curve B at an intermediate point, and tangent to curve C at the 90-deg. level. Likewise, the section of mirror between 109 and 120 deg. has a characteristic G tangent to the 109-deg. level, doubly tangent to B, and tangent at the upper end of C.

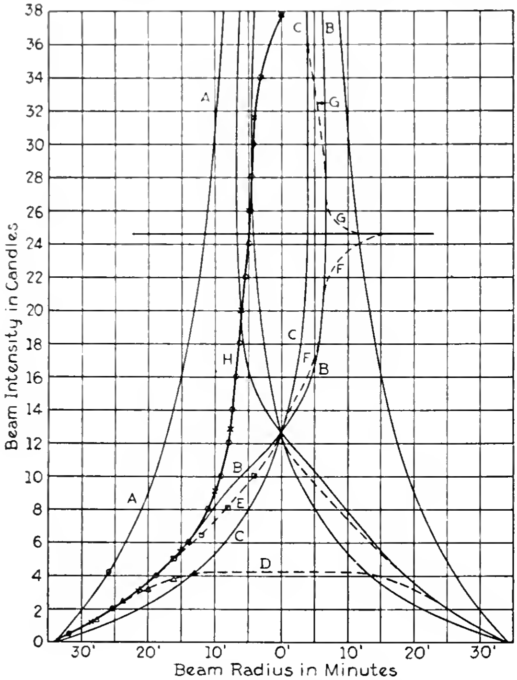

Fig. 77. Curve *A*—The maximum dimensions of the elemental images give a characteristic identical with that of a spherical source
B—The characteristic derived from the average diameter of the image
C—The characteristic derived from the minimum diameter of the elemental image
D—Beam from a 60-deg. mirror
E—Beam from a 90-deg. mirror. Derived from curves *B* and *C*
F—Beam from mirror section from 90 to 109 deg.
G—Beam from mirror section from 109 to 120 deg.
H—Beam from a 120-deg. mirror from summation of *E*, *F* and *G*

The summation of the three beams, E, F, and G, gives the solid curve H on the left of Fig. 77. The crosses on this curve are from Fig. 75 and show that with the section beams drawn as in the illustration, the agreement with the exact curve is complete.

With a little practice in drawing the dotted curves, it is probably possible to get the beam characteristic of any depth of mirror with a fair degree of accuracy, and this method, in spite of the open gaps in the data, is therefore of some use as a first approximation.

Characteristic at Short Range

If we think of the beam of light from an arc searchlight in terms of the elemental images of which it is composed, the reason for the change in shape of the intensity curve at various ranges becomes at once apparent. The final beam formation is completed only when the distance between the centers of the extreme edge beams becomes negligible in comparison with the total beam width. At lesser ranges, there is a spurious width in nearly all parts of the beam and by a simple extension of the method for getting the zonal image from the elliptical elemental image, the beam characteristic at any range may be computed graphically. This will complete the study of the beam from a disk source as it gives us information about that section of the sides of the beam that was left untouched by the geometrical investigation and was covered for a special case by the last few sections on graphical construction.

As a starting point, let us investigate the distribution of light in a beam from a source of radius 0.01 in a mirror of unity focal length at the point where the curved edge of the beam begins for a 45-deg. mirror. It is worth pointing out that with this angle the inverse-square region begins at exactly the same distance. This range, therefore, has considerable importance as one might be tempted to try to analyze the beam from a 45-deg. mirror at a point where the full central intensity is first realized and where the excess width may be computed.

For an angle a of 45 deg., we have

$$L_o = 137 \text{ focal lengths}$$

The center of each zonal beam is computed by equation (43) and the major and minor axes (the latter always on a radial line with the searchlight axis) are computed by equations (114) and (115).

In Figs. 78 to 89 inclusive, the zonal images are computed for each 10-deg. zone up to 120 deg. It might have been advisable to have used narrower zones for angles beyond 90 deg. but for purposes of exposition the loss in accuracy of construction is not of great importance.

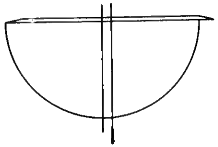

Fig. 78. *Elliptical elemental* image for 6 deg. 40 min. angle below the horizontal axis, and 0 deg. to 10 deg. *zonal* image above the axis for a range of 137 *F*

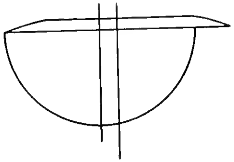

Fig. 73. 15-deg. *elemental* image and 10-deg. to 20-deg. *zonal* image at a range of 137 *F*. The axis of the beam and zonal image is on the right and the axis of the elemental image is on the left

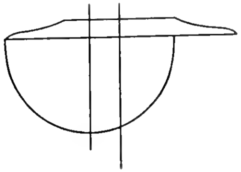

Fig. 80. *Elemental* image from 25-deg. position and *zonal* image from 20-deg. to 30-deg. zone. The increasing heights of zonal images correspond to the increasing zone area

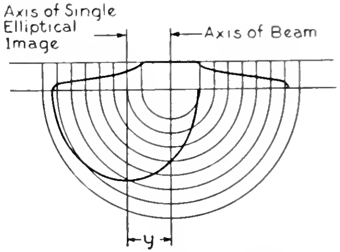

Fig. 81. Construction details for deriving the 30-deg. to 40-deg. *zonal* image from the 35-deg. *elemental* image at a distance *y* from the axis

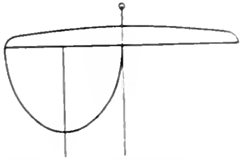

Fig. 82. The point over the center of the zonal image (40 deg. to 50 deg.) indicates full intensity on the axis only and less than half intensity in all other parts of the zonal beam

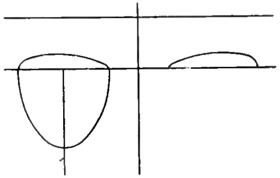

Fig. 83. The zonal image from the 50-deg. to 60-deg. zone is annular in form and of about one-third full intensity, as indicated by the height of the image as compared to the line above the horizontal axis

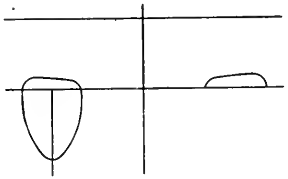

Fig. 84. The opening in the center of the 60-deg. to 70-deg. zonal image is half the diameter of the image and the intensity is less than a quarter the full intensity

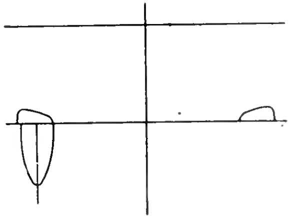

Fig. 85. Zonal image from 70-deg. to 80-deg. zone. An observer at a distance 137 *F* will see only one-fifth of the zone luminous at one time

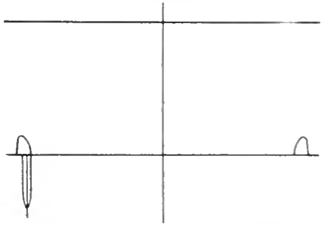

Fig. 86. The elemental image from 85 deg. is almost a straight line, and the maximum beam width is determined by points near the end of the major axis

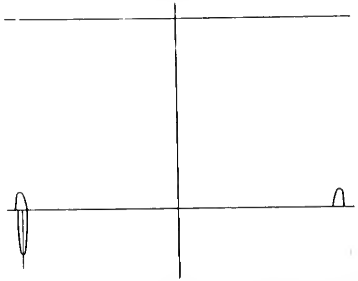

Fig. 87. The elemental image from 95 deg. gives a weak annular beam of large radius and small thickness

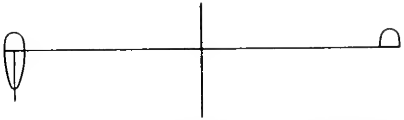

Fig. 88. The elemental image at 105 deg. is rounder than at 85 and 95 deg., and the zonal image intensity is about the same intensity as from the previous zone

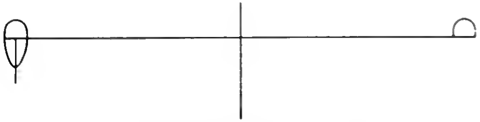

Fig. 89. Zonal image from the 110-deg. to 120-deg zone derived from the elemental image at 115 deg.

The center of the elliptical elemental image, Fig. 81, is displaced by the radial distance *y* which is constant at all distances along the beam. The actual linear dimension of the image at 137 focal lengths and the relation between center of image and center of beam are plotted to scale in the illustration, and a series of evenly spaced semicircles are drawn concentrically about the beam axis. The proportion of each semicircle included within the ellipse is measured and this proportion is used as a factor to reduce the height of the zonal image immediately above the construction semicircles. Except for the separation of the two axes and the use of evenly spaced semicircles in place of evenly spaced radial lines, the method is the same as previously used for finding the zonal images from the elliptical beams.

The images from the zones beyond 50 deg., Fig. 83, etc., are annular in form, and attention is called to the great reduction of intensity in these annular images below the intensity of the normal concentrated zonal image. In the particular case of the 90- to 100-deg. image, the reduction is to one eleventh, and the 110- to 120-deg. image is reduced to one twenty-fifth.

In Fig. 90, the twelve zonal images are assembled for adding. The addition of the first six gives the characteristic shown by the dotted line. Later, a comparison of this curve and the corresponding curve of Fig. 75 will be made for the purpose of showing the precise effects of distance upon the beam formation. The beam intensities at double the distance, that is 275 focal lengths, is given in Fig. 91 along with the zonal images. The elliptical images of Figs. 78 to 89 were used after reducing the distance between axes to half in every case. A doubling of the range makes each image twice as wide, and therefore the constant distance between axes is in proportion reduced to one half. The graphical solution must of course be repeated in each case.

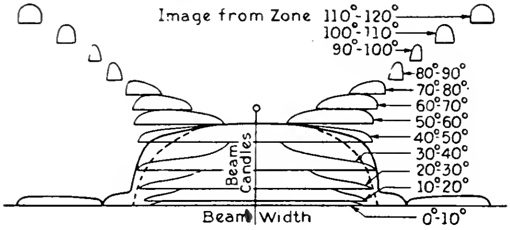

Fig. 90. Zonal images arranged for summation for beam formation at 137 *F*. The dotted curve is the beam from the 0-deg. to 60-deg. sections. The solid curve to where it first approaches the horizontal axis is the 0-deg. to 90-deg. beam. The outer sections of the solid curve are the annular beam from the 90-deg. to 120-deg. mirror section

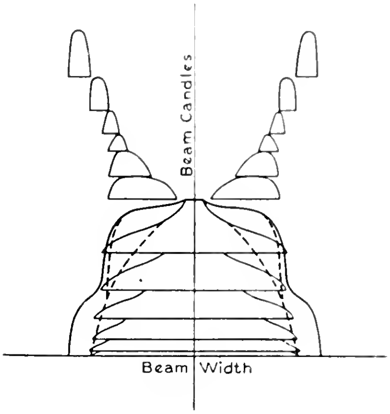

Fig. 91. At a range of 275 *F*, the 0-deg. to 60-deg. section gives a beam of nearly normal appearance. The 60-deg. to 90-deg. section adds to the shoulder of this beam, and the 90-deg. to 120-deg. section adds to the outer parts only, giving the solid curve for the characteristic of a 120-deg. mirror

A further doubling of the distance to 550 focal lengths gives the characteristic of Fig. 92, and at 1100 focal lengths the curves are as in Fig. 93. The progressive closing in of the annular zonal images results in greater central intensities and a narrowing of the upper part of the beam. The triple maxima

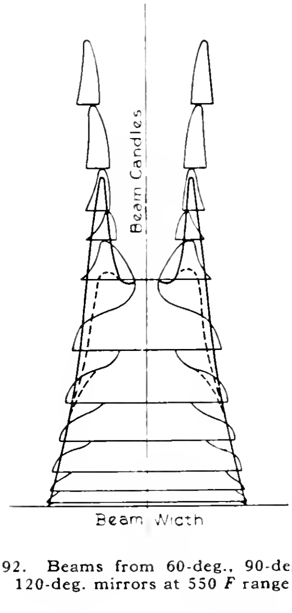

Fig. 92. Beams from 60-deg., 90-deg. and 120-deg. mirrors at 550 *F* range

at the longer ranges is an interesting feature that has appeared a number of times in an incipient form in the testing of 60-in. searchlights at 2300 ft.

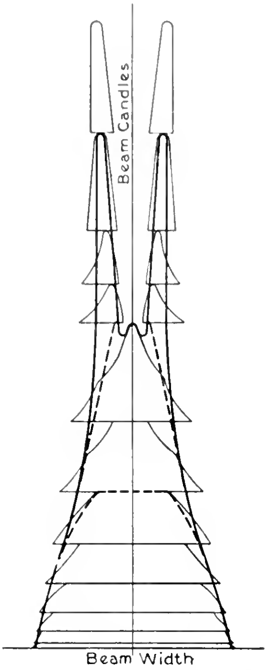

Fig. 93. Beam formation at 1100 *F*. The 60-deg. mirror gives a beam of almost normal form but the wider mirrors give beams that are characteristic of this range only

The manner in which a beam changes in form at increasing range is illustrated in Figs. 94, 95, and 96 where the characteristic curves of beam intensities are plotted for three mirrors of 60 deg., 90 deg., and 120 deg., respectively, and of equal focal lengths. The beam from the 60-deg. mirror comes fairly rapidly into final form (which is here taken from Fig. 75) and the range of 1100 focal lengths gives a curve that can barely be distinguished from the final form at extreme distances.

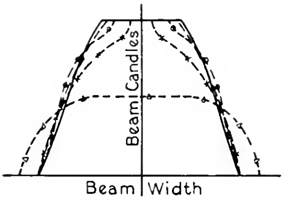

Fig. 94. The progressive change of beam formation at 137 *F*, 275 *F*, 550 *F*, 1100 *F* and infinity are here illustrated for a 60-deg. mirror

At short range, the crest of the 60-deg. beam is either missing in its full intensity or reduced in width. The crest gets wider as the range increases, but never exceeds the final width. The edge of the beam, at the point of zero intensity, first exceeds the final width but quickly decreases to about its final value; but keeps always on the outer side of that point. There is a region near the top of the curves where the beam is first too narrow, then too wide, so that in this region there is always a reasonable doubt as to the direction of error in a test, unless of course we solve that particular combination of source and mirror in a manner similar to the particular case of Fig. 94.

The beam from the 90-deg. mirror comes to its final form very slowly, and here the last point to come into practical agreement is the central point of the beam. This is a result of the shape of the image given by the 90-deg. zone, and if reference is made to the curves of Fig. 50 (showing the increase for a different combination of source and mirror) it will be seen that no further finite increase of range

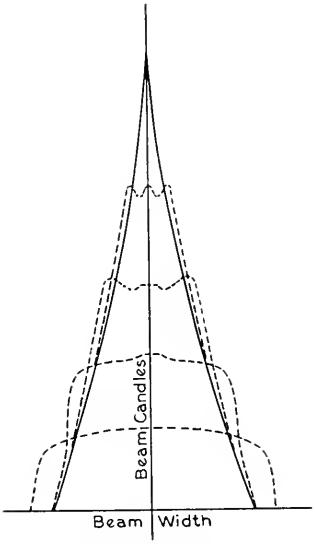

Fig. 95. A 90-deg. mirror gives a beam characteristic that is sharply pointed but the test distance must greatly exceed 1100 *F* as shown by the upper dotted curve compared with the solid curve for infinity. The lower dotted curve is for a range of 137 *F*, and the three above it are for distances of 275 *F*, 550 *F* and 1100 *F*

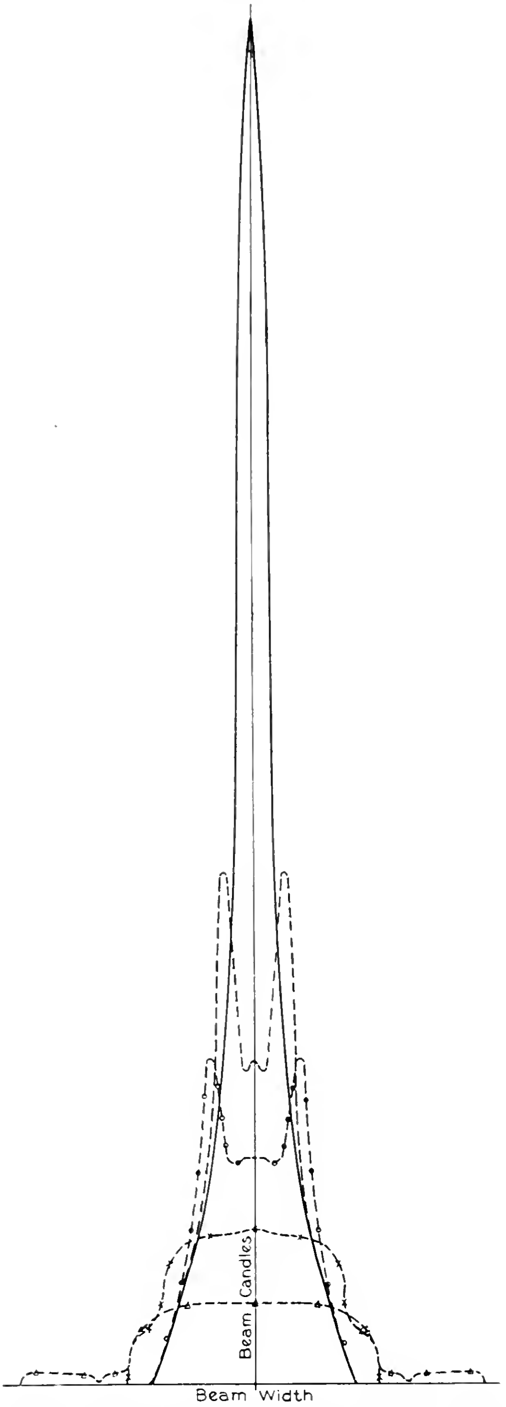

Fig. 96. The progressive alteration in the distribution of light in the beam is illustrated by this series of curves. For each doubling of the test range the central intensity is increased by a constant amount. After one or two further doublings of the distance there will be a sudden increase and then a slower increase for additional ranges. The changing rate of increase is due to the introduction of an active outer zone on the mirror as was illustrated for the spherical source

will bring the central intensity up to its full maximum.

The two very pronounced peaks on the sides of the 120-deg. beam, Fig. 96, are traceable to the same geometrical relations that gave the outer zone of light in the mirror of Fig. 51. The light from this active outer zone is still confined to the outer part of the beam at the greatest range here considered, and very greatly increased ranges must be used to make these annular zones join on the axis. The data of the 120-deg. mirror of Figs. 50 and 51 were for a beam of a source of radius 0.0962 F, while we are here considering a source of radius 0.01 F. The equivalent of the 1100 focal-length distance for the larger source is 1100 divided by 9.62 (the ratio of beam widths) and multiplied by 2.60 (the ratio of focal lengths). This gives 297 in. on the 120-deg. curve of Fig. 50. This is less than half the distance where light from the outer zones of the mirror reaches the axis and where the sharp rise in intensity takes place; and accordingly no further marked increase in the central heights of the curves of Fig. 96 can be expected short of a range of 2500 focal lengths; and a reasonably close approach to the final maximum does not occur until the range is between 5000 and 6000 focal lengths.

Computation of Beam Characteristic

It was shown in the description of the "Curve Method of Deriving the Beam Characteristic," page 821, that at best only a part of the beam characteristic curve followed the curve for the average width of the zonal image. Any formulas based on the same images must have the same limitations, and we get by our computations the curves of Fig. 71 and not those of Fig. 77. As has been mentioned several times, the accuracy of the curve from the average zonal image is good for mirrors of 60 deg. or less but there is a great loss of accuracy when the mirror contains a 90-deg. zone.

The mirror must first be considered as made up of three sections, and to avoid confusion, let the mirror angle in the 0-deg. to 90-deg. section be designated by a_1, the angle in the section from 109 deg. 28 min. to 90 deg. be denoted by a_2, and mirror angles higher than 109 deg. 28 min. be denoted by a_3.

Equations for points on the three sectional beams are therefore

$$\left.\begin{aligned} C_{a_1c.} &= \frac{57.28r}{F}(1+\cos a_1)\sqrt{\cos a_1}\text{ deg.} \\ I_{a_1} &= 4\pi\ Bk\tan^2\frac{a_1}{2}\text{ candles} \end{aligned}\right\} \quad (116)$$

for the first section, and

$$\left.\begin{aligned} C_{ave.} &= \frac{57.28r}{F}(1+\cos a_2)\sqrt{\cos a_2}\text{ deg.} \\ I_{a_2} &= 4\pi\ Bk\ (2-\tan^2\frac{a_2}{2})\text{ candles} \end{aligned}\right\} \quad (117)$$

for the second section. The value 2 in the bracket is the square of the tangent of one half 109 deg. 28 min. The third section has the equation

$$\left.\begin{aligned} C_{ave.} &= \frac{57.28r}{F}(1+\cos a_3)\sqrt{\cos a_3}\text{ deg.} \\ I_{a_3} &= 4\pi\ Bk\ (\tan^2\frac{a_3}{2}-2)\text{ candles} \end{aligned}\right\} \quad (118)$$

In using these equations, it is necessary to plot the individual sectional beams because the values of I_{a_1}, I_{a_2}, and I_{a_3} cannot be added unless they fall at the same angle in the beam, that is, $C_{ave.}$ must have a common value. They can have a common value only if a trial solution is made for equal values of $C_{ave.}$ (which is a long operation) or if the curves of Fig. 73 are used to pick out equal values.

Testing Distance for Entire Characteristic

In dealing with arc searchlights of the larger sizes, the required testing distance sometimes extends into thousands of feet and a new factor enters. This is the absorption of light by the atmosphere. If the absorption were uniform in all parts of the beam, we could measure the quantity of light at short range and again at long range and correct the characteristic curve at long range by a constant factor to compensate for the loss in the atmosphere. The actual problem is not so simple because it has been found that there is a progressive alteration in beam formation that is in addition to the orderly geometrical phenomenon already discussed. This additional change arises from the selective absorption and scattering of light by the atmosphere combined with a change in color composition between the center and the edge of the beam. As a rule, the edges of the beam are richer in blue and violet light, and these are the colors that are most quickly absorbed by the atmosphere. The result is a narrowing of the beam that might possibly deceive the experimenter into thinking that the searchlight was in some manner improperly focused.

Two views may be taken of the practical importance of this phenomenon. We may take the view that if service conditions require long ranges then the test should be taken at the service distance. The difficulty here is that the phenomenon of narrowing and otherwise changing is dependent both in nature and degree upon the precise condition of the atmosphere. We know, of course, that the atmosphere goes through all kinds of variations in its transmitting properties and therefore we could not after all hope to have the test and service conditions agree.

The other way of looking at the matter is to find the beam formation under conditions where the influence of the atmosphere is a minimum and thus eliminate one unknown quantity. This requires a short test distance and we must therefore establish a minimum distance that will give data of satisfactory accuracy.

Take first the case of a plain carbon arc with a 60-deg. mirror. If reference is made to the characteristic curves of Fig. 94 the greatest deviation of intensity and width is seen to occur near the shoulders of the curves where the inverse-square region joins the sloping sides. This is directly related to the width of the inverse-square region itself, and equation (54) should therefore be our guide in all cases where we are free to choose the testing range. In Fig. 94, the short range curve that best agrees with the curve for an infinite distance is at a distance of nearly $4L_o$ from the searchlight. In Fig. 94, the upper finite range curve is at 1100 focal lengths while $4L_o$ for this 60-deg. mirror gives 1200 focal lengths.

It would not do to attempt to make a fixed rule for all projectors for the reason that in many cases L_o is infinite, and we must therefore look for other data on which to form an estimate in the particular case of mirrors extending to 90 deg. In Fig. 95, the beams are all considerably below the theoretical maximum, but it must be remembered that the sharp point to the limiting curve is based on a mirror accuracy that belongs in the realm of the optics of astronomy and is never encountered in searchlight practice. A moderate scattering of light in the center of the beam will increase the intensity of the adjacent points and thus mirror defects will tend even at extreme testing distances to give the upper triple-peaked beam of Fig. 95, and this wider beam will of course not be so sensitive to change in range. Just as an arbitrary rule, we may therefore take L_e for our base of computation and make the testing range $4L_e$ when L_e is computed for the 90-deg. zone of the mirror. For the 90-deg. mirror of Fig. 95, this would call for a testing distance of 1600 focal lengths.

A mirror of wider angle than 90 deg. naturally requires a greater range than one of just 90 deg. but this additional distance will perhaps not be great and at a maximum $6L_c$ would seem to be sufficient. The peak of the ideal curve greatly exceeds the best short range curve of Fig. 96, but in any actual case the great concentration of energy in the center of the beam cannot be maintained and the working range for this mirror is brought within more reasonable limits.

(Series to be continued)

The Mounting of Diamonds by the Casting Method

By Howard Miller

Head of Testing Laboratory, Fort Wayne Works of General Electric Company

The importance of correct setting of diamonds used for truing abrasive wheels cannot be over emphasized, for incorrect setting probably is responsible for more loss of stones than any other cause. A correct setting of any stone involves two major factors. First, the stone must be so placed that the best cutting point is available for use, included in which operation is a proper orientation of the stone to minimize shattering. Second, the stone with the exception of the small point exposed for use should be securely anchored.

Many schemes have been developed for mounting diamonds and it goes without saying that there are a number of successful methods in everyday use. However, all of them require expert knowledge gained only after long experience. This is always true of the correct placing of the stone which constitutes the greatest problem in setting. The mechanical operation of anchoring the stone is also important; and it is the purpose of this article to describe an anchoring method which it is felt will be of interest to everyone using diamonds for the purpose under consideration.

It is evident that the most secure mounting is that in which the diamond is entirely surrounded by a relatively hard and tough material, impervious to the heat generated during the truing process. This of course requires pouring or tamping around the diamond a material having a sufficient degree of fluidity to conform to the contour of the stone, and has usually been done either by molten metal or mercury amalgams. The use of molten metal, especially the operation known as brazing where brass is used, subjects the diamond to a more or less high temperature with the possibility of doing harm to the stone unless great skill and care is used. The use of lower melting point alloys is therefore to be recommended.

In the method about to be described, the diamond is properly held by supporting wires and placed in the bottom of a split mold similar to a bullet mold. The stone and mold are then slowly heated to about 350 deg. F. The mold is then poured full of molten alloy which has previously been melted in the small electric furnace shown in Fig. 1. This alloy, familiar to the trade as Sampson Metal, is a mixture of

Zinc	90 per cent
Copper	5 per cent
Aluminum	5 per cent

It has a melting point of about 650 deg. F., and a Brinell hardness of about 78. Thus its relatively low melting point permits casting at temperatures that will not hurt the stone and at the same time the material is sufficiently strong and hard to hold the diamond properly.

In developing a suitable alloy, a number of different varieties were made the subject of experiment, especially those of the aluminum series. This series was first suggested because aluminum has a somewhat lower melting point than brass. It was soon found that stones set in pure aluminum loosened and chattered after being used a short time; and on cutting open the nib, it was seen that air pockets had developed at the rear of the diamond which resulted in its becoming loosened. This was mainly attributed to the diamond having floated slightly when the aluminum was poured into the nib. The diamond was then anchored securely in the bottom of the bullet mold by means of copper wire. Better results were obtained but still the diamond would loosen slightly, due apparently to the characteristic softness of pure aluminum. A copper hardened aluminum was then tried and the results were much better. However, the melting and pouring characteristics of the aluminum alloys are somewhat critical, especially in such small castings as these. Efforts were then directed to the zinc series. The best results were obtained by the use of the zinc-copper-aluminum mentioned; and it is believed that the relative ease with which this alloy can be melted and poured together with a fair degree of hardness, recommends it for this class of work. Fig. 2 shows sections of diamond settings made with this alloy. It will be noted that the diamond is firmly embedded in the nib.

Fig. 1. Electric Arc Furnace Supplied with Energy from the Standard Compensarc in the Foreground. The combination is here employed for melting the alloys in which abrasive diamonds are mounted

The furnace shown in Fig. 1 is built up of fire brick and refractory cement so constructed as to hold a small graphite crucible. Two carbons are inserted through the refractory wall, one from each side, and by means of a standard Compensarc an arc is drawn between the crucible and the electrodes which quickly melts the metal in the crucible. This type of furnace has been found very convenient for melting small quantities of alloys both in an experimental way and for limited production. It provides a clean, ready source of heat; and as the current is easily controlled, the heat can also be controlled so that once the metal is melted it can be kept molten at any temperature desired by controlling the current. The life of the crucible is very good and the expense of renewal is nominal. It has been found that about a five-eighth inch diameter white flame cored carbon for one electrode and an extremely hard carbon for the other gives the best operating results. The carbons are hand controlled, and to start the furnace it is only necessary to bring them in contact with the crucible and draw them away slightly. It is possible to melt a charge of the alloy in about 15 min., after which the current can be regulated to maintain the proper pouring temperature. The convenience of a melting furnace of this type can be appreciated in connection with work such as the setting of diamonds where its use is only intermittent. It always is ready for use, will melt a charge very quickly, and when the work has been done it is only necessary to pull a switch.

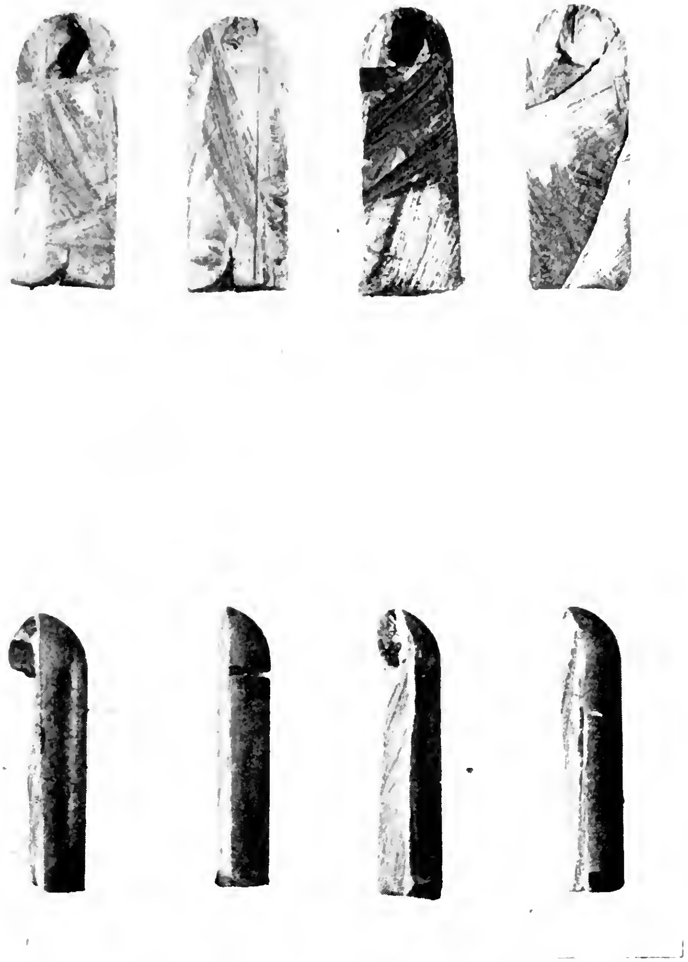

Fig. 2. Sections of several diamond mountings produced by the method described in this article

The Temperature and Brightness of Tungsten Lamps

By W. E. Forsythe

Nela Research Laboratory, National Lamp Works of the General Electric Company

After some general remarks on the brightness and temperature of incandescent lamp filaments the author describes the three different ways of measuring the brightness of tungsten. Valuable data are given in the four tables in the article.—Editor.

Tungsten lamps are now manufactured in a great variety of sizes and types and the different sizes and types are not all operated at the same temperature In general the higher wattage lamps are operated at higher temperatures. As a result of measurements made in Nela Research Laboratory for various purposes over a period of several years, considerable data have been accumulated on the temperature and brightness of tungsten lamps.

The filament of a vacuum tungsten lamp unless it is a miniature lamp is practically all at the same temperature and thus at the same brightness. There is, it is true, a portion of the filament near the leads and supports where the temperature is lower than the main part of the filament. That the integral effect of this difference in temperature is not very marked is seen when the color temperature of such a lamp is measured first as a whole and then with the ends screened so as to cut off the light from the cooled portion. For an ordinary vacuum lamp the difference in color temperature for the ends screened and the ends unscreened is only about 9 deg. for 2500 deg. K, the color temperature corresponding to about 10 lumens per watt. This, however, is not the case for a miniature vacuum lamp or gas-filled lamp where the temperature of the filament is not as uniform.

The energy loss from the heated filament of a gas-filled lamp, due to the surrounding gas, has been shown* to depend upon the diameter of the filament, being relatively much smaller for the larger filaments. To get the effect of a large diameter with a small wire the filament of a gas-filled lamp is coiled in the form of a helix. This has been found to have about the same effect in reducing the gas loss as would result from a filament of the same diameter as the coil.

There are two reasons why the higher wattage gas-filled lamps have a higher efficiency than the smaller lamp of this type. In the first place the larger filaments can be wound in larger helices and still be strong enough to keep their shape throughout their life. Also the larger wire can be operated at a higher temperature, since a small amount of evaporation from the surface does not affect the resistance of the large filament as much as it does the smaller one.

In this article, whenever the temperature of a lamp is given it is to be understood that the maximum temperature of the filament is meant. The values given, in general, represent the average of a number of measurements on a number of different lamps.

The temperatures given in this article are on the scale adopted by the General Electric Company for use in its laboratories.† This temperature scale is based upon the assumption of Wien's equation with c_2 taken as 14350μ deg. and upon the melting point of gold taken as 1336 deg. K. (deg. C.+273). On this scale the melting point of palladium has been found to be 1828 deg. K. For convenience in the calibration of optical pyrometers, a black body held at the melting point of palladium is used as a point of reference.

When measuring the temperature of a lamp filament it is necessary to use some form of optical or radiation pyrometer. If the temperature of the filament is not uniform or if for some reason the temperature of only a small portion of it is desired, the disappearing filament optical pyrometer is the best type to use.

Practically all solid substances when heated to a sufficiently high temperature begin to glow, giving off at first a very deep red light of low intensity. As the temperature is raised the intensity of the light increases very rapidly and at the same time the color changes first to lighter red, then to an orange, etc., tending to approach white at higher temperatures. Although the brightness of any source that is heated depends upon its temperature, all substances are not equally bright at the same temperature. Black objects that absorb practically all the radiation they receive when cold are, when at a high temperature, brighter than other

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*Langmuir: *Jour. A.I.E.E.*, xx, p. 1910, 1913.

†Hyde, G-E Review, xx, p. 819, 1917.

objects that reflect a large portion of the light they receive when cold. Thus one should not expect a bright metal like tungsten to emit as much light per unit area at a high temperature as carbon which is black at ordinary temperatures. The amount of light emitted per unit area is not, however, the sole measure of efficiency. This depends upon how the substance radiates both in the visible and infra-red portion of the spectrum.

The standard of radiation is the "black body" that theoretically absorbs all the radiation that it receives. It has been shown that the black body radiates so that the following equation, for values of the product λT less than 3000, represents the relation between the temperature and the intensity of the energy radiated for a particular wavelength interval

$$\left[E_\lambda = c_1 \lambda^{-5} e^{-\frac{C_2}{\lambda T}}\right]$$

where E_λ is the energy intensity, λ the wavelength expressed in μ, and T the temperature in degrees Kelvin, C_1 and C_2 being constants. For the visible spectrum, where the longest wavelength is in general less than 0.8μ, T, the temperature can have a very high value and still the product λT be less than 3000. Thus this equation is satisfactory to use for this region of wavelengths for as high temperatures as are ordinarily dealt with. A cavity with walls at a uniform temperature containing a small opening for observation approximates very closely the ideal black body.

All other bodies, when the radiation is due to thermal causes alone, are less bright than the black body at the same temperature, not only for the total radiation but for the different wavelengths. This is expressed in the form of an equation as follows:

$$\left[E'_\lambda = \epsilon_\lambda' c_1 \lambda^{-5} e^{-\frac{C_2}{\lambda T}}\right]$$

where E'_λ is the energy intensity for the wavelength interval with center at λ and ϵ_λ, which has a value less than unity, is the emissive power of the substance studied. The emissive power depends not only upon the substance studied but may vary with both the wavelength and temperature. From this equation it is very evident that if the emissive power is known for any wavelength the temperature can be determined from a measurement of the energy intensity for the same wavelength interval. Worthing,* by making a black body of a tungsten tube with a small radial hole for observation and mounting this in a lamp bulb so as to heat it electrically, was able to determine the emissive power of tungsten for different wavelengths and different temperatures. He measured the true temperature from observations through the small hole and the relative brightness of the black body and tungsten at the same temperature by observations through the hole for the black body and on the outside of the tube for the tungsten brightness.

The temperatures of the various lamp filaments were measured using a disappearing filament optical pyrometer having as the monochromatic screen a red glass. This glass transmits enough light so that accurate measurements can be readily made for temperatures as low as that of melting gold (1336 deg. K.) and is sufficiently monochromatic so that photometric balances can be made accurately even when there is a temperature difference of 1500 deg. C. or more between the source and the pyrometer filament.

An optical pyrometer gives the relative brightnesses of the surfaces compared. If the temperature of a particular substance is determined from its brightness as if it were a black body, too low a value for the temperature will be obtained, since, as was mentioned above, no known radiator is as bright as the black body when at the same temperature. Such temperatures are called brightness temperatures and will in general be different for different wavelength intervals. Thus when a brightness temperature of say 1500 deg. K. for $\lambda = 0.665\mu$ is given, it means that the substance as studied has the brightness of a black body at 1500 deg. K. for $\lambda = 0.665\mu$.

The brightness temperatures of tungsten obtained by the use of the optical pyrometer were reduced to true temperatures by making use of the emissive powers of tungsten that have been determined by Worthing by the method outlined above. The true temperature and brightness temperature are related as follows:

$$\frac{1}{T} - \frac{1}{S} = \frac{\log \epsilon_\lambda \,.\, \lambda}{C_2 \log e}$$

where T is the true temperature and S and ϵ_λ the brightness temperature and the emissive power corresponding to the wavelength λ.

The temperature and brightness of the filaments of some of the lamps with bulbs

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*Phys. Review, N. S. X, p. 377, 1921.

that are not transparent was determined either by measurements on the lamps before they were made non-transparent or by having filaments of the same kind mounted in clear bulbs and operated at the same voltage in the clear bulb as in the other bulb. If the filaments had exactly the same dimensions they should be operated so as to be at the same resistance rather than at the same voltage for the same temperature. For the filaments that were studied the average of the results on the resistance for the same voltage were higher in the clear bulbs than in the other bulbs, which is contrary to what might be expected. The brightness temperature of some of the lamps with blue bulbs was measured using a blue glass as the monochromatic screen of the optical pyrometer. These brightness temperatures were then reduced to true temperatures using the known data on tungsten.

TABLE I

TEMPERATURE AND BRIGHTNESS OF VACUUM LAMPS

Lamp	Lumens per Watt	Temperature °K.	Brightness $\frac{\text{Candles}}{cm^2}$
50-watt carbon.......	3.3	2115	55
50-watt gem.........	4.0	2180	78
50-watt tantalum.....	4.9	2160	53
10-watt tungsten.....	7.7	2355	128
25-watt tungsten.....	9.8	2450	191
40-watt tungsten.....	10.3	2475	212
60-watt tungsten.....	10.3	2475	212

Knowing the temperature of the tungsten filament it is of course possible from the known data to get its brightness in candles per square centimeters. When the brightness of a light source is spoken of, in general, what is meant is the maximum brightness. The inside of the coil of a gas-filled lamp is much brighter than the outside. This is due to the fact that the brightness of the inside of a particular coil is made up of the regular radiation from the inside of that coil and radiation from the inside of other coils that seem to come from this coil by repeated reflections. The brightnesses of the filaments of the different types of lamps as well as the brightness of the inside of the coils for the large lamps were measured. The outside brightness of the bulb for some of the frosted and sprayed lamps was measured.

These brightnesses were measured by one or more of three different methods. The first was the direct method where the candlepower of a filament of known length and cross section or a definite area of the bulb was measured and from such data the brightness calculated. The second method was to measure the brightness of the different sources with a disappearing filament optical pyrometer used as a brightness photometer.* In this case the glass used as a monochromatic screen was one that had an effective wavelength about equal to the Crova wavelength for a particular temperature interval and changed about the same amount as does the Crova wavelength for different temperature intervals. The Crova wavelength is defined as the wavelength for which the monochromatic change in brightness for a particular temperature interval is the same as the brightness change for the entire visible spectrum. Thus it is possible to measure relative brightnesses using the Crova wavelength, without having trouble due to color difference. Since it was impossible to get a glass that would give exactly the Crova wavelength, corrections had to be made where the difference in wavelength became large. Knowing the effective wavelength of the glass, the Crova wavelength and the color temperature of the source, such corrections could readily be made.

TABLE II

BRIGHTNESS OF TUNGSTEN AT VARIOUS TEMPERATURES

Temperature	Lumens per Watt	Brightness
1800	1.2	5.2
1900	1.9	10.4
2000	2.7	20.2
2100	3.8	35.8
2200	5.3	61.7
2300	6.9	105.0
2400	8.9	155.0
2500	11.2	234.0
2600	13.6	343.0
2700	16.9	482.0
2800	19.8	679.0

The third method, applicable only to filaments of uniform temperature, was to measure the color and brightness temperatures and making use of the known brightness of the black body to compute the brightness of the filament thus measured. The color temperature of a source is defined as the temperature at which it is necessary to operate a black body so that the light from the black body will have the same integral color as that from the source studied. This

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*Jour. of Franklin Institute, 1923.

means in general that the source studied and the black body have the same distribution of energy in the visible spectrum. In general, however, when operating at the same color the black body will be brighter than other sources, that is, each ordinate of the curve representing the energy of the source studied will be some fraction $(1/K)$ of the corresponding ordinate of the black body. Thus the brightness B_s of the source studied is given by

$$B_s = \frac{B_{BB}}{K}$$

where B_{BB} is the brightness of the black body at a temperature the same as the color temperature of the source studied, and K is given by the following equation:

$$\log. K = \frac{C_2 \log e}{\lambda}\left(\frac{1}{T_C} - \frac{1}{S}\right)$$

where T_c is the color temperature of the source studied and S the brightness temperature corresponding to wavelength λ.

The three methods outlined above have been used in a determination of the brightness of tungsten as a function of temperature. The values thus obtained agreed within experimental error. The brightnesses given in this article were measured by two of the above methods, whenever it was possible. For some of the brightnesses it was only possible to use the second method, that is the optical pyrometer calibrated as a photometer.

TABLE III

TEMPERATURE AND BRIGHTNESS OF VARIOUS GAS-FILLED TUNGSTEN LAMPS

Lamp	Lumens per Watt	Temperature °K.	Color Temperature °K	Brightness of Filament Candles cm^2
Regular Gas-filled Lamps				
50-watt	10.0	2685	2670	462
75-watt	11.8	2735	2705	546
100-watt	12.9	2760	2740	597
200-watt	15.2	2840	2810	778
300-watt	16.3	2855	2830	802
500-watt	18.1	2930	2920	1000
1000-watt	20.0	2990	2980	1195
2000-watt	21.2	3020	3000	1295
Special Lamps				
1000-watt stereopticon	24.2	3185	3175	2018
900-watt movie	27.3	3290	3220	2636
10 kw.	31.0	3350	3300	3034
30 kw.	31.0	3350	3300	3034
Daylite Lamps				
200-watt	10.0	2860		
500-watt	11.2	2960		
Photographic				
750-watt		3065		
1500-watt		3105		

The relation between the efficiency of an ordinary vacuum tungsten lamp as a light source and also its brightness in candles per square centimeter and temperature is given in Table I. The temperatures and brightnesses were measured far enough away from a lead or support so as not to be affected by the cooling due to conduction of the leads. If the values of the efficiency given were corrected for end losses, they would be about eight per cent higher.* At a temperature of 2450 deg. K. the tungsten lamp has an efficiency of about 10 lumens per watt and a life of about one thousand hours. As the temperature is increased the life is decreased very rapidly until at about 2800 deg. K. the life would only be about seventy hours.

In Table II the efficiency of some of the vacuum tungsten lamps is given. For comparison data are included on carbon and tantalum lamps. These lamps are all operated at such an efficiency that the life will be one thousand hours. The 60-watt tungsten lamp that was in use a few years ago operated at about 7.8 lumens per watt for a life of one thousand hours. A comparison of this value with that given in the table will show that the efficiency has been increased about thirty per cent. This increase

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*Worthing: *Jour. Franklin Inst.* 194, p. 608, 1922.

has been brought about by more refined and better controlled processes of manufacture.

In Table III some data are given on the efficiency, temperature and brightness of some of the present day gas-filled lamps. The lamps listed in the first part of the table are some of the regular clear gas-filled lamps. They are operated at such a temperature that they have a life of one thousand hours. In column four are given the color temperatures of some of these lamps. The color temperature is about twenty to thirty degrees lower than the true temperature. This is because the color temperature is for the whole lamp while the true temperature refers to the hottest part of the filament. A comparison with Table II will show how much it has been possible to increase the efficiency by raising the temperature and still maintain the one thousand hours' life by the introduction of an atmosphere of an inert gas. The lamps on which data are given in the second part of the table are for special purposes. They are operated at a temperature that will give either the desired brightness or efficiency. In general they do not have as long a life as the regular lamps. The 10- and 30-kw. lamps are some special lamps that were designed and constructed by the Lamp Development Laboratory of the National Lamp Works for some special studio motion picture work. These lamps are constructed with four coils in the same plane. The plane covered by the coil of the 10-kw. lamp is about 4 by 5 cm., while that of the 30-kw. lamp is about 7 by 11 cm. It is interesting to note that the 10-kw. lamp has an intensity of about 40,000 candles in a direction perpendicular to the coils while the 30-kw. has an intensity of about 100,000 candles in the same direction. This means that the 10-kw. lamp would give the same illumination at a distance of two feet from the plane of the coils as is received from the sun in mid-summer. The 30-kw. lamp would give this same illumination at a distance of about 3½ feet from the plane of its coils. Since the temperature of the lamp is much lower than the sun the amount of heat received from the lamps at this distance is much greater than from the sun.

TABLE IV

BRIGHTNESS OF FILAMENTS AND BULBS OF SOME TUNGSTEN LAMPS TOGETHER WITH THE BRIGHTNESS OF SOME OTHER SOURCES FOR COMPARISON

Lamp	Brightness Measured at	Brightness Candles $\frac{}{cm^2}$
Kerosene flame	Flat wick	1.2
4-watt per candle carbon lamp	Filament	55.0
40-watt vacuum tungsten lamp	Filament	212.0
40-watt vacuum tungsten lamp	Bulb frosted	2.5
40-watt golden Mazda	Bulb	2.0
50-watt White Mazda	Filament	408.0
50-watt White Mazda	Bulb	1.3
75-watt White Mazda sprayed	Filament	546.0
75-watt White Mazda sprayed	Bulb	2.1
2000-watt gas-filled Mazda	Filament	1295.0
2000-watt gas-filled Mazda	Between coil	3000.0
2000-watt gas-filled Mazda	Bulb frosted	130.0
Sun as observed at earth's surface		165,000.0
Clear sky, average		0.4

The temperatures in the third part of the table are for some of the lamps with blue bulbs called daylite and photographic lamps. The daylite lamps are operated at a temperature somewhat higher than the corresponding sizes in the clear bulbs so that their life is seven hundred and fifty hours. The photographic lamps are operated at a slightly higher temperature than the daylite lamps in order to increase their intensity in the blue end of the spectrum.

In Table IV are given data on the brightness of the bulbs and filaments of some of the tungsten lamps with some other sources included for purposes of comparison. The data show how much the maximum brightness of the different lamps is reduced by frosting or spraying the bulb.

Ten Years of Voltage Standardization

By M. D. Cooper

Engineering Department, National Lamp Works of General Electric Company

The advent of the drawn-wire tungsten lamp enabled the manufacturer to make lamps of predetermined standard voltages. The author shows the result of ten years' work on the standardization of voltages in the lamp industry.—Editor.

That any industry to be successful must fulfill certain definite obligations with respect to the use of its products, is axiomatic. Fortunately, soon after the introduction of the drawn-wire tungsten filament lamp about 13 years ago it was recognized that the standardization of circuit voltage, which of course would lead to a standardization of lamp demand, was one of the most important problems confronting the lighting industry.

It is generally understood that the wide spread in central station voltages in the early days was due to the inability of manufacturers to make lamps to a specified voltage. As new stations were placed in operation they selected such odd voltages as would best utilize the manufacturers' product. Most of these voltages fell within the 100-130 volt range. With the coming of the drawn-wire tungsten lamp, and improved methods of manufacture whereby lamps could be made accurately to a predetermined voltage, the whole order of things was changed and the work of standardizing was actively started.

The problem with which central stations were confronted was not one to be solved in a day. It involved a thorough engineering study and analysis of every phase of lighting and power practice—the generation and distribution of energy, as well as the electrical characteristics of all the many forms of current consuming apparatus using the service. The immensity of the problem is indicated by the fact that in many cases central station operating voltages had to be changed as much as 10 volts one way or the other in order to establish any basis of standardization. It had to be shown conclusively that readjustments of this magnitude were justified from the purely economic standpoint.

Although progress in voltage standardization has of necessity been slow, much has been accomplished in the last decade. Of greater importance, however, is the increasing evidence that the idea is fundamentally sound. Standardization of voltages is just as logical and just as desirable as standardization of lamp bases and of lamp types, both of which have contributed in no small part to the tremendous growth of the lighting load in this country. Only recently, lamp engineers have made an intimate study of the lighting development of several leading foreign countries. This study clearly revealed the fact that the lack of standardization both in operating voltages and in types of lamps had been a serious hindrance to the development of the foreign lighting business. The effect of higher prices, slower deliveries, and the general inconvenience attending the use of any non-standardized product was plainly evident. The lamp consumption of seven of the leading foreign countries is less than two-thirds of a lamp per capita per year as compared to a figure of about two lamps per capita in the United States,—a disparity which is in itself conclusive evidence that foreign peoples have not had full opportunity to use light economically.

In order to facilitate the work of voltage standardization, lamp manufacturers have for a number of years distributed as a guide to lamp supply a record of the operating voltages of individual central stations in this country. In Table I these figures are compiled and an interesting analysis of conditions is shown. The first three lines of this table show the number of communities and the corresponding total population in which the electric service is so closely regulated as to require only one lamp voltage for the entire community, and in which the voltage is a standard voltage, that is, 110, 115 or 120 volts. From the standpoint of public lamp supply, these communities are the only ones which may be called completely standardized and, even here, there is a possibility that small isolated plants in these communities may require a lamp voltage differing from the standard of the central stations. It will be noted, however, that 91.5 per cent of the total number of communities are served under this condition of one standard central station voltage for the entire community; this corresponds to 83.5 per cent of the total population within reach of electrical service.

A further study of this summary indicates that future efforts must be directed not only toward converting odd and high voltages (200-260 volts) to one of the three standard voltages but also toward the *unification* of service voltages in communities where more than one voltage is now used. The difficulty encountered in handling a stock of lamps of various voltages and in distributing the proper lamps to specified districts of a community, through the regular commercial channels, can be readily understood. It is also well recognized that the purchaser cannot be expected to differentiate between lamps which look exactly alike but which nevertheless will render vastly different degrees of satisfaction on his circuit. The solution of this distribution problem lies in unification of voltages.

Although the percentage of communities in which unification of service voltage at a single standard has not been accomplished is small (about 10 per cent of the total), the customers adversely affected by this non-unification represent nearly 20 per cent of the total population to which electric service is available. To effect this unification, changes of 5 volts in many cases and of 10 volts in a few cases will be required.

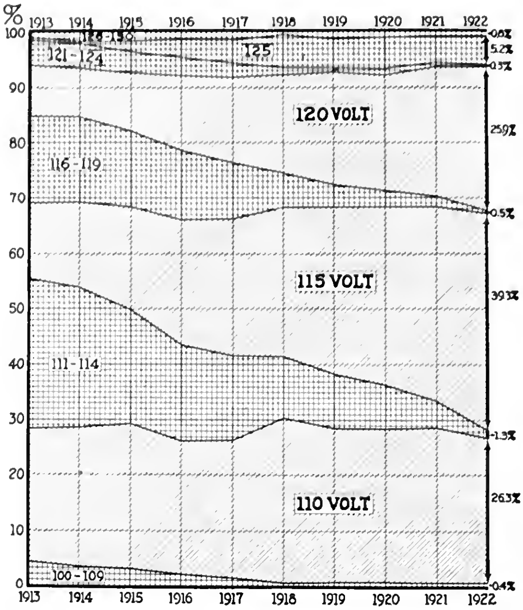

Fig. 1. Ten Years of Voltage Standardization

To summarize, it is significant that from the standpoint of *standardization only* and without regard to *complete unification*, 95.2 per cent of the communities, representing 96.7 per cent of the electrical population, is served at one or more of the three standard voltages; these figures compare with 74.1 per cent and 71.8 per cent respectively only four years ago.

One of the handicaps of the early voltage standardization movement was the lack of

TABLE I

AN ANALYSIS OF CENTRAL STATION PRACTICE BY LAMP VOLTAGES

Lamp Voltage Recommended by Central Station	Number of Communities		Per Cent of Total		Population of Communities (1920 Census)		Per Cent of Total	
110 volts only	6,976		47.7		21,360,400		33.9	
115 volts only	5,221		35.6		24,282,400		38.4	
120 volts only	1,198		8.2		7,147,600		11.2	
Total, one standard voltage only		13,395		91.5		52,790,400		83.5
More than one standard voltage, one station	434		3.0		1,405,100		2.2	
More than one standard voltage, more than one station	106		0.7		6,961,100		11.0	
Total, standard voltage(s) only		13,935		95.2		61,156,600		96.7
112 volts only	118		0.8		333,500		0.5	
125 volts only	88		0.6		189,100		0.3	
Other voltage below 130 volts	162		1.1		667,100		1.1	
200 volts or higher	259		1.8		250,500		0.4	
Standard and odd voltages, one station	59		0.4		337,000		0.5	
Standard and odd voltages, more than one station	17		0.1		318,000		0.5	
Grand Total		14,638		100.0		63,251,800		100.0

information which would indicate in some degree the ultimate standard toward which central station practice was tending. It was in view of this situation, together with the fact that in some cases wide readjustments in central station voltages were physically and commercially impracticable (some stations were unable to raise their voltage above 110 volts owing to the limitations of their equipments while others could not greatly decrease their voltage without considerable increase in line copper) that the three voltage centers, 110, 115, and 120 volts, were selected for lighting service. Fig. 1 is therefore of interest in this connection, charting as it does the course of lamp demand in the 100-130 volt class for the past ten years. The chart is of historic interest in that it shows the tremendous progress made in eliminating odd voltages; in the ten-year period represented, the demand for lamps of odd voltages has decreased from over 50 per cent of the total demand in 1913 to less than 10 per cent in 1922. Of greater practical value, however, is the establishment of the trend toward a single voltage standard. Although 110 volts gave considerable evidence of becoming the predominant standard, the 115-volt demand has been making steady inroads into the 110- and 120-volt classes and now exceeds either of the other two standards by at least 13 per cent. When all things are considered there is every reason to believe that 115 volts will become the ultimate standard for lighting service.

A New Type of Overload Protective Relay

By A. B. Campbell

Fort Wayne Works of General Electric Company

The author describes some new types of temperature or thermal overload relays. After some instructive remarks on the general principles involved he describes the construction and then the operation. In conclusion, he lists the more important features of the device described.—Editor.

During recent years the problem of overload protection for electrical machines has been demanding more attention because stricter requirements are now placed on devices performing this service.

In studying this problem it is found that the greatest overall economy in operation results when the equipment is worked at its maximum rated capacity, provided always that interruptions due to accidental overloads under this condition are of rare occurrence. Overload protective relays, therefore, should allow maximum usefulness of equipment and yet give positive protection against all dangerous overloads.

The type of relay described in this article is designed to fulfill these requirements and is based on the thermal principle of protection, involving operation by machine temperatures. Since this factor alone, in the great majority of cases, determines whether or not a given overload is dangerous to the equipment, this method of operating the protective device is fundamentally correct in principle. The actual temperature, at any instant, of a piece of electrical equipment under load includes a time measurement as well as a load measurement and therefore depends to a great extent on the condition of load previous to the measurement as well as on the ambient temperature surrounding the machine and on many other factors. The thermal protective relay takes all of these variable factors into account and operates to remove load from the equipment when the temperature of the machine reaches a predetermined value, usually between 90 and 100 deg. C.

The same results as are obtained by this type of control could be accomplished by temperature indicators located at various places in the machine, but to be practical in the sense of general application to all sizes of machines the device must be entirely external to the machine and yet must indicate machine temperatures reliably. The method used in thermal relays to obtain this result is to build the relay so that it has a time-load temperature characteristic exactly duplicating that of the machine which it is desired to protect; in other words, the relay is built to have the same thermal time lag for all loads as the machine. The relay is then subjected to the same load as the machine by being connected in series with it, and therefore its temperature follows exactly the variations of the machine temperature. Upon reaching the ultimate operating temperature, regardless of the time required, the device functions to operate the control contacts, disconnecting the equipment from the load.

Variations in ambient temperature affect the relay as well as the machine, so that assuming the device to be adjusted to operate normally in an ambient of 40 deg. C. with a 50 deg. C. rise, it will allow the equipment to carry greater than normal loads for all ambients less than 40 deg. C. and less than normal loads for all ambients above 40 deg. C., always limiting the ultimate temperature to a predetermined value. With this adjustment it would be impossible to operate the machine at any load in an ambient of 90 deg. C., if this was selected as the maximum operating temperature.

Machine temperature in this connection refers to the temperature of the machine and the time-load characteristic refers to a curve experimentally determined showing the time required for the machine to reach a predetermined ultimate temperature for various overloads under a constant set of conditions.

General Construction and Operation

In actual construction the relay consists of three principal elements functioning together as follows:

1. A strip of thermostatic metal of fixed size and resistance, which responds to the relay temperature;
2. A heat storage volume having definite thermal constants determined by its size, shape, and material;
3. A heating unit of fixed resistance mounted in a space provided in the heat storage block.

The thermostatic metal strip performs two functions: first, it is the actuating means and operates the contacts by virtue of its property to assume a definite position for a predetermined temperature of the relay; and second, it is constructed so that it is part of the load circuit. Its constants, resistance and heat storage volume are so proportioned that it forms the high speed element of the relay, largely determining the shape of the high overload portion of the time-load characteristic. The high speed element predominates at the high overload portion of the curve, while its effect becomes less pronounced on decreasing overloads until at the critical value the shape is determined by the constants of the heat storage blocks. These two actions merge smoothly together on changing overloads and form the complete characteristic.

The heat storage volume of definite capacity gives the relay the required time lag at low overloads and its constants, size, specific heat, heat conductivity, and ratio of volume to radiating surface, determine the slope of the lower portion of the time load temperature characteristic.

The heating unit supplies heat to the thermal storage volume at a rate dependent upon the load on the machine, the ratio of resistances of the heating unit and thermostatic strip determining the shape of the time-load temperature characteristic, as will be shown later.

An assembled view of a single-element device is shown in Fig. 1. In this view the thermostatic metal strip is seen mounted in intimate thermal contact to the heat storage blocks which are electrically insulated as a convenient means of electrically separating the ends of the strip. The circuit through the device is through both heater and strip in series, the heater being located in the round longitudinal hole through the centers of the blocks.

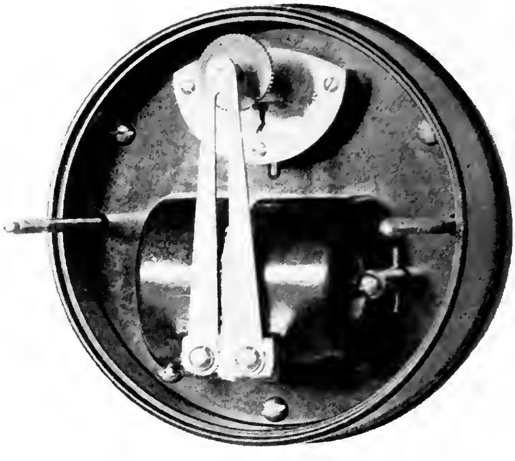

Fig. 1. Single-element, Thermal Type of Overload Protective Relay

In the single element device the simplest form of contact arrangement is shown; i.e., a single contact at the end of the thermostatic metal strip touches a stationary but adjustable contact in the base at the contacting temperature (90 deg. C.). This arrangement can be made either circuit closing or opening simply by reversing the direction of deflection of the thermostatic metal strip, i.e., having it move toward or away from the stationary contact on increasing temperature. The adjustment of the stationary contact provides a means of changing the contacting temperature.

The simple contact arrangement shown in Fig. 1 is not used as a direct line control, but is used for making or breaking an alarm circuit or a circuit controlling the operation of an auxiliary relay which in turn controls the main line. This latter construction is used in two thermal type of protective relays, which are provided with an auxiliary relay within the case allowing an automatic resetting feature. In the simpler forms of relays having push button or other hand reset mechanisms, the thermostatic metal strip is used as a mechanical latch holding a pair of spring mounted contacts closed under normal operating conditions and allowing them to open at the predetermined temperature of operation on overloads.

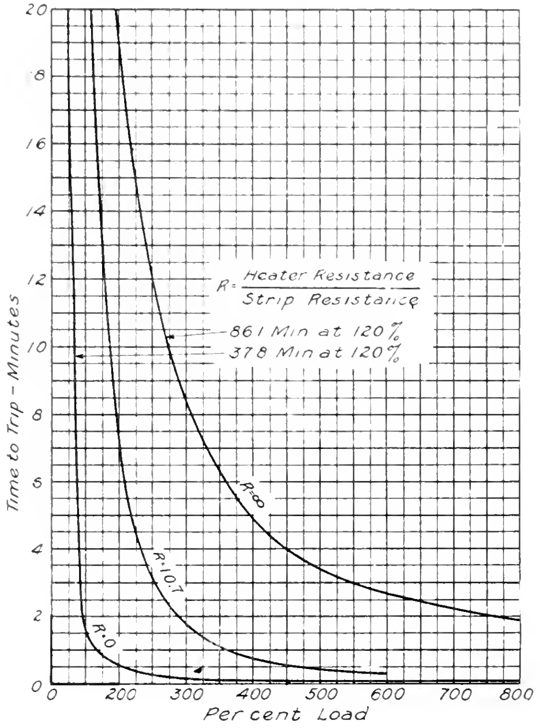

Fig. 2. Thermal Time-Load Characteristic Curves of the Relay for the two limiting ratios of heater resistance to strip resistance and for an intermediate value

In operation the device functions as follows: On all loads some heat is developed in the device, but on normal loads the thermostatic metal strip does not reach its operating temperature. On low overloads the temperature of the whole device is gradually raised to the operating temperature by heat developed in the heating coil and transmitted to the strip through the thermal storage blocks. Under this condition the rate of heat generation in the strip itself by the load current is lower than the rate of heat absorption by the blocks, hence the strip follows the block temperature; on high overloads, however, the rate of heat generation in the strip is greater than the rate of absorption by the blocks, so that the strip builds up temperature within itself and since its heat storage volume is relatively small, its operating temperature is reached in a very short time. This is analagous to what actually happens in a piece of electrical apparatus under load; low overloads gradually raise the temperature of the whole mass while high overloads generate heat in the windings so much faster than it can be absorbed by the frame that they reach a dangerous temperature in a very short time. Permitting the analogy to be carried a little farther, it may be said that the windings in the machine are duplicated in the relay by the thermostatic metal strip while the machine frame is represented by the thermal storage blocks.

Duplication of Thermal Time-Load Characteristics

As was indicated above, the thermal relay operates on a time-load characteristic which is a duplicate of the characteristic curve of the machine being protected.

The characteristic curve of this relay is the resultant of two thermal characteristics; one adjusted by proper lagging to give the required time on relatively low overloads, and the other adjusted for proper times on high overloads. After these two elements have been adjusted for the proper values, they are combined thermally and the resultant curve is the characteristic desired.

The method by which this is accomplished is shown clearly in Fig. 2. Two curves are plotted in this illustration showing the shift in the time-load characteristic between the two extremes of the value of the ratio of heater resistance to strip resistance; in one case, R = infinity, where the thermostatic metal strip was omitted from the circuit entirely, and in the other case R = zero, where the thermostatic metal strip was the only part of the device in the circuit. Any time load characteristic falling between these two extremes may be duplicated simply by determining the proper ratio of resistances of these two elements. The curve in Fig. 2 marked R = 10.7 is plotted from data taken on a relay having a ratio of heater resistance to strip resistance of 10.7.

Characteristics not included between these two limiting curves will lie between two similar curves plotted from data on a similar device having different time-lag characteristics due to a change in dimensions or material of the thermal storage reservoir. The new characteristics may then be duplicated as just shown.

By the use of these various modifications it is therefore possible to duplicate any actual thermal time-load characteristics of electrical equipment.

Since the output of some direct-current machinery is limited by commutation difficulties beyond certain loads rather than excessive temperature rise, it has been necessary to further modify the design to obtain a time-load characteristic which would give complete protection to the equipment. For rotary converters, temperature rise limits the length of time the machine may carry loads up to about 170 per cent while beyond this point the time is limited by commutation. The thermal relay for rotaries, therefore, has a characteristic which is a combination of two curves; one a duplicate of the thermal characteristic of the machine for all loads below 170 per cent, and the other a thermal inverse-time characteristic of very steep slope which is intended to remove the machine from service after very short intervals for all loads over 170 per cent, this curve giving much shorter times for these loads than would be required only by temperature rise considerations. Under operating conditions (40 deg. C. ambient temperature and 90 per cent continuous load) this relay requires 2 hours to trip at 150 per cent load, while at 200 per cent load it will trip in 2.5 minutes, giving a ratio in times of 48:1. Under the same operating conditions another variation of the thermal relay, used for fractional h.p. motor protection, gives times to trip for the loads mentioned above of 1 minute and 0.6 minute respectively, or a ratio of only 1.67:1. These two examples illustrate the possibility of thermal characteristic curve duplication by thermal relays over extreme conditions.

The theory and design of the relays described in this article are the result of research and development directed by Mr. Chester I. Hall of the Fort Wayne Works, and many devices embodying these principles are in actual service in connection with automatic generating and substation equipment, and many industrial motor applications. A special device for application to domestic motor appliances has also found extensive use.

Throughout this discussion it has been assumed that the heating and cooling characteristics are practically identical, as they are in the case of a transformer, and under this condition the temperature of the relay is always the same as that of the machine even though the machine may be performing special duty cycles such as rolling mill loads, etc., where the peak load in each cycle is of very high value.

The motor equipment of electric locomotives presents a more complicated problem because of the fact that the equipment may be subjected to different rates of cooling, depending on whether the cooling takes place when the locomotive is stationary or coasting. In the latter case the forced ventilation results in rapid cooling which must be duplicated in the relay by special ventilation in order that the relay may follow the motor temperature variations.

The use of thermal overload protection properly designed for a given installation results in many advantages which are not obtainable by any other means. The more important features are given below:

The equipment is protected from overheating for any and all conditions of load.

The maximum overload ability of the machine is utilized without danger.

The capacity of the equipment is automatically varied between proper limits for changes in ambient temperature.

Interruptions of service due to overloads are reduced to a minimum and maximum possible intervals are allowed for carrying overloads over temporary peaks.

Thermal relays are self-protective and are not harmed by overloads when properly installed because of the fact that they trip at a predetermined temperature.

Thermal relays are applicable to either alternating current or direct current without modification.

These devices are particularly useful in induction motor operation since they may be set to trip on small overloads and yet allow sufficient time for starting even though the motor may require several times full load current under this condition.

The application of this new principle to overload protective relays is fundamentally correct and it is anticipated that thermal protection will find a wide field of usefulness.

The Electron in Chemistry

PART IV

By Sir Joseph John Thomson
Master of Trinity College, Cambridge, England

In this, the concluding article of this series, the author deals with Oxygen; Diamagnetism; Electron Theory of Solids; Divalent Elements; Trivalent Atoms; Tetravalent Element; Hexagonal System; Compressibility of the Metals; The Energy and Compressibility of Divalent Elements; The Compressibility of a Trivalent Element; Surface Tension; Communication of a Charge from Gaseous Ions to the Electrodes; Intermetallic Compounds and Mixed Crystals and Intermetallic Compounds. We again acknowledge our indebtedness to the Journal of the Franklin Institute for permission to reprint this remarkable series of articles.
—Editor.

Oxygen

The most fascinating of all magnetic bodies is to my mind oxygen. Here we have one of the simplest of atoms; its atom contains only eight electrons, it is a gas, and therefore in the simplest of all physical states, and yet it alone of all gases is paramagnetic and quite strongly so. Another remarkable thing about it is that innumerable as are the compounds of oxygen there is only one, NO, into which oxygen carries its magnetic properties. This would seem to suggest that the magnetic quality does not arise from some quality intrinsic to the atom, but from some specialty in the arrangement of the colligating electrons in those molecules where it exhibits its magnetic character. The oxygen molecule itself is the most conspicuous example; the arrangement of the electrons may be represented symbolically as two cubes having a face in common, this face being at right angles to the line joining the atoms. If the system were rotating about this line there would be an odd number of square faces in rotation. A rotating square with its electrons would act like a current and thus behave like a magneton. Now suppose that the rotation of electrons must be such that adjacent squares rotate in opposite directions, and it is evident that if we start one from rest in one direction, the adjacent one will start in the opposite direction. Suppose then that the electrons in the planes of the squares were rotating so that the rotation in one plane is opposite to that in the adjacent plane, then two of these planes will be rotating in one direction and the third in the opposite, the resulting magnetic effect will be the same as if only one plane rotated, and this will produce a magnet of finite moment.

It might be thought that if this arrangement of electrons were all that is required to produce paramagnetism, a considerable number of gases would be paramagnetic, whereas so far as is known only two possess this property. The consideration of the arrangement of the electrons in gaseous compounds shows, however, that the configuration of O_2 is almost unique in this respect. Consider the arrangement of electrons in some compounds of oxygen, *e.g.*, in water where it is in combination with two monovalent atoms, the electrons are arranged in an octet which has *two* sets of four electrons in parallel planes, if adjacent sets rotate in opposite directions, the total magnetic effect will be zero. The same is true for a compound like CaO, or for one like CO_2, where there are four such sets. We see that whenever the oxygen atom occurs, as it always does in valency compounds, with two additional electrons forming an octet, the effect of one face of the octet will always balance that of the other. In a neutral *atom* of oxygen the electrons would be arranged at the corners of an octahedron; if this were to rotate about one of its axes, the four electrons at right angles to the axis would form an unbalanced system and this would have magnetic properties. The magnetic properties of NO, if we take the arrangement of the electrons to be as that given in the first lecture, would arise from the rotation of the three electrons inside the octet, those on the octet itself would not contribute to the magnetic properties. In the compound C_2H_4 we have a similar arrangement of electrons to those in O_2, but in C_2H_4 all the massive positive charges are not as they are in O_2 on a straight line. The result of this is that if the two octets rotate, say about the line joining the two carbon atoms, they would either have to carry the hydrogen atoms with them, in which case the moment of inertia would be enormously increased, or else move the electrons relative to the hydrogen atoms; the forces between the positive charges and the electrons would resist this motion, and tend to stop the rotation. In the oxygen molecule the electrons can rotate while the positive parts are at rest. If the compounds NCl or NF existed, the arrangement of the electrons would be as in O_2, and on the views we have been expressing we should expect that these compounds would be magnetic.

Diamagnetism

The diamagnetic properties of chemical compounds will furnish, I think, many searching tests of any theory of the distribution of electrons among the atoms of the compound. According to the theory of diamagnetism given by Langevin,[29] the contribution of an atom to k, the coefficient of diamagnetism, is equal to $\frac{1}{4}\,\frac{e^2}{m}\,\Sigma r^2$, where $m\Sigma r^2$ represents the moment of inertia of the electrons in the atom about an axis through their centre of figure. The distribution of electrons is supposed to be quite symmetrical so that the moments about all axes are equal, e is the charge and m the mass of an electron.

If n is the number of atoms per unit volume, k, the coefficient of magnetization is given by the equation

$$k = \frac{1}{4} n \frac{e^2}{m} \Sigma r^2 \tag{32}$$

If M is the molecular weight of the system, $\triangle$ the density of the substance, N the number of hydrogen atoms in a gram of hydrogen

$$n = \frac{\triangle}{M} N \tag{33}$$

hence

$$\frac{kM}{\triangle} = \frac{1}{4} \frac{e^2}{m} N \Sigma r^2 \tag{34}$$

Thus $kM/\triangle$, which is called the atomic diamagnetic coefficient and is denoted by X_a, is proportional to Σr^2, and when X is known Σr^2 can be calculated. We pass on to consider, what, for our purpose, is the most important application of diamagnetism —the connection between the diamagnetic coefficient of a compound, and those of its constituents.

Pascal[30] has made a series of most valuable experiments on this point, chiefly on organic compounds. He finds that the connection between X_m, the diamagnetic constant of a compound $A_x B_y C_z$ and X_a, X_b, X_c, the constants for its constituents, is expressed by the relation

$$X_m = xX_a + yX_b + zX_c + \lambda \tag{35}$$

where λ is a quantity, generally small compared with X_a, X_b, X_c, which depends on the "bonding" of the atoms. Thus, for example, when oxygen is one of the constituents of the molecule, the value of λ, when the oxygen is connected by two linkages with a carbon atom, is not the same as when the oxygen is connected by one link with a carbon and by another to a hydrogen atom; thus, for example, the contributions of the two oxygen atoms in formic acid HCO.OH are different.

Pascal was dealing with valency compounds; in these, on the electron theory, the atom of any particular element will be associated with the same number of electrons whatever may be the compound in which it occurs; thus, for example, the electronegative elements O, S, F, Cl, will always be surrounded by an octet of electrons; the outer layers of the electropositive elements will have been transferred to the electronegative ones to make up their octets. An interesting point arises here in connection with the hydrogen atom and to a less extent with metal atoms. In a compound of hydrogen with an electronegative element, the electron associated with the hydrogen atom has gone to make up the octet round the negative ion, as, for example, in HCl. Thus the hydrogen atom in such a compound is but a positive core, it has no electrons associated with it, and hence on the electron theory of diamagnetism would not contribute anything to the diamagnetic coefficient. Pascal, however, in deducing the coefficient for any compound, assigns to hydrogen a constant value. This is to some extent a matter of bookkeeping, the electrons transferred from the hydrogen to the chlorine will increase the contribution of the chlorine atom to the diamagnetic coefficient. If we like we may transfer this increase to the credit of the hydrogen atom and regard the hydrogen atom as making a contribution to the diamagnetic coefficient, though it does this not by acting itself as the centre of one of the molecular currents, which account for diamagnetism, but by furnishing an electron which increases the molecular currents in some other atom. We should, however, expect that the amount of the increase would depend upon the kind of atom to which the electron is transferred, that it would increase with the radius of this atom and thus be greater for bromine than for fluorine or chlorine.

We shall now consider what relation would be indicated on the theory we are considering between the diamagnetism of a compound

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[29] *Annales de Chimie et de Physique* [8], 5, 70 (1905).

[30] *Annales de Chimie et de Physique* [8], 25, p. 289.

and of its constituents. On the view that, at any rate, in valency compounds there is a transference of electrons from one atom to another, the atoms in the compound are not in the same state as when they were free and uncombined. The atoms of the electronegative elements such as oxygen or chlorine have gained electrons, while those of the electropositive elements have lost them. The coefficient of diamagnetism is proportional to the sum of the moments of inertia of the electrons about an axis through their centre of figure parallel to the magnetic force. If the transference of the electrons involves a change in this moment the coefficient of diamagnetism will be altered by chemical combination, *i.e.*, the additive law will not hold.

Suppose that in the free state the distances of the electrons from the centres of the atoms of the elements A and B are r_a and r_b, respectively, and that the electrons are symmetrically distributed. Then if there are α electrons on A, β on B the coefficient of diamagnetism is proportional to

$$\frac{2}{3}\,\alpha\,r_a^2+\frac{2}{3}\,\beta\,r_b^2. \qquad (36)$$

If as the result of chemical combination α atoms are transferred from A to B, if R_b is now the distance of the electrons on the B atoms from its centre the coefficient of diamagnetism is now

$$\frac{2}{3}\,(\alpha+\beta)R_b^2 \qquad (37)$$

This may be written in the form

$$\frac{2}{3}\alpha\,r_a^2+\frac{2}{3}\beta\,r_b^2+\frac{2}{3}\alpha\left(R_b^2-r_a^2\right)+\frac{2}{3}\beta\left(R_b^2-r_b^2\right) \qquad (38)$$

the sum of the first and second terms is the value given by the additive law, the remaining terms represent corrections which must be applied to obtain the diamagnetic coefficient of the compound. If X_{AB} represents this coefficient, we see

$$X_{AB}=X_A+X_B+\alpha\lambda_{AB}+\frac{2}{3}\beta\left(R_b^2-r_b^2\right) \qquad (39)$$

when $\lambda_{AB}=\frac{2}{3}(R_b^2-r_a^2)$ and is a function which involves the dimensions of each of the atoms at the ends of the bond binding them together. The term $\frac{2}{3}\,\beta\,(R_b^2-r_b^2)$ depends only upon the atom B, hence the equation may be written as

$$X_{AB}=X_A+X'_B+\alpha\lambda_{AB} \qquad (40)$$

where X'_B depends only upon the properties of the B atom.

Applying the same reasoning to the most general case, we see that X the value for the compound $A_xB_yC_z$ will be given by an equation of the form $X=xX\ (A)+yX\ (B)+zX\ (C)+\Sigma\lambda_{AB}$.

A term has to be introduced into $\Sigma\lambda_{AB}$ for each electron transferred, *i.e.*, for each valency bond in the compound. Thus we may regard the diamagnetic coefficient of a compound as consisting of a series of terms, one set depending on the atoms in such a way that each atom contributes a definite amount depending only upon the atom; the second set of terms depending on the valency bonds, each bond contributing a term, the value of which depends upon the dimensions of the atoms at the ends of the bond. There may be a term in this set even when the atoms at the ends of the bond are the same; for example, when we have single or double bonds between two carbon atoms: For from the expression for λ we see that they would not vanish unless the radius of the octet round the carbon atoms in the compound $C-C$ was equal to the distance of an electron in a free carbon atom from the centre. As the radius of the octet, round the carbon atoms when there is a double bond $C=C$ is not the same as when there is only a single bond, the value of λ for a double bond is not necessarily twice that for a single one.

Pascal found that a double bond produced a very appreciable *diminution* in the diamagnetism, the magnitude of the effect of the double bond was about equal in magnitude, though opposite in sign to that due to a single carbon atom. The effect of a triple bond was much smaller than that of a double one.

Pascal's researches on the diamagnetism of compounds show that what we have called the λ terms are not in general large compared with the atomic ones, yet these terms undoubtedly exist. He shows, for example, that the contribution of oxygen to the diamagnetic coefficient is not the same, when as in CH_3OH the oxygen is linked by one bond to the carbon and by another to the hydrogen as it is in CH.O.OH, where one of the oxygen atoms is linked by two bonds to the carbon atom; he shows, too, that the contributions of doubly and singly linked carbon atoms are different; he shows in fine that to calculate the diamagnetic coefficient of a compound we must take into account the constitution and configuration as well as the chemical composition.

In addition to the effects produced by the bonding of the atoms, there are others, though probably not so important, arising from what may be called the compressibility of the cell of electrons surrounding the atoms. Thus, for example, it is probable that the distance of the electrons from the centre of the chlorine atoms in HCl is not quite the same as in CCl_4, where the four chlorine atoms may compress each other by their mutual repulsions. A change in the dimensions of the atom would give rise to a change in the diamagnetic coefficient.

The corrections due to the λ terms amount in some cases to as much as 30 per cent, though it is exceptional for them to be as large as this.

From the equation

$$X_a = -\frac{1}{4}\frac{e^2}{m}N\Sigma r^2 \qquad (41)$$

we can, if we know the value of X_a, deduce the distance of the electrons from the centre of the atom. For if the distribution of the electrons in the outer layer is symmetrical about the centre

$$\Sigma r^2 = \frac{2}{3}nR^2 \qquad (42)$$

where n is the number of electrons in the outer layer and R the distance of these from the centre of the atom; hence

$$X_a = -\frac{1}{6}\frac{e^2}{m}NnR^2 \qquad (43)$$

or since $e/m = 1.87 \times 10^7$; $e = 1.6 \times 10^{-20}$; $N = 6.16 \times 10^{23}$

$$X_a = -3.06 \times 10^{10} \times R^2 \times n. \qquad (44)$$

Pascal[31] gives the following values for $-10^6 X_a$.

H	2.93	Al	13.2	As	43	Te	37.5
Li	4.20	Si	20.0	Sc	23	I	44.6
Bc	8.55	P	26.3	Br	30.5	Cs	41.0
B	7.30	S	15	Rb	27.2	Ba	38.2
C	6.80	Cl	20.1	Sr	24.5	An	45.8
N	5.57	K	18.5	Ag	31	Hg^{II}	33.4
O	4.61	Ca	15.0	Cd	20	Pt	40.3
F	5.95	Cu	18	In >	15	Pb	45.8
Na	9.2	Lu	13.5	Sn^{iv}	30.3	Bi	192
Mg	10.1	Ga	16.8	Sb^{iii}	74.0		

From these values of X_a we find from the preceding equation the following values for the diameters of fully charged electronegative atoms. The values found by W. L. Bragg[32] are given for comparison.

Element	Diameter from Diamagnetic Constant	Values Found by Bragg
O	1.02×10^{-8}	1.30×10^{-8}
F	1.05×10^{-8}	1.35×10^{-8}
S	1.84×10^{-8}	2.05×10^{-8}
Cl	2.0×10^{-8}	2.10×10^{-8}
Se	2.23×10^{-8}	2.35×10^{-8}
Br	2.40×10^{-8}	2.38×10^{-8}
Te	2.8×10^{-8}	2.66×10^{-8}
I	3.0×10^{-8}	2.80×10^{-8}

The agreement between the values of the diameters found from the diamagnetic coefficient and those found by Bragg is fairly close. It is interesting to note that there is nothing exceptional in the value of the strongly paramagnetic element oxygen; from this we conclude that the oxygen atom when it has two additional electrons is not paramagnetic.

When the diamagnetic substance is in a solid state a somewhat different treatment is required. If it is a metal, the electrons will be arranged in lattices and along these lattices the electrons may be free to move. If these lattices form a simple cubical system, then it can be shown that the effect of the electrons on the lattices in a plane at right angles to the magnetic force is to produce per unit area of this plane a magnetic moment equal to $-\frac{1}{16}\frac{He^2}{m}$, when H is the magnetic force, if d is the distance between two parallel lattice planes the moment due to the electrons in unit volume is $-\frac{1}{16}\frac{He^2}{md}$, hence the coefficient of diamagnetism is equal to $\frac{1}{16}\frac{e^2}{md}$.

Since the radius of an electron is of the order e^2/m, we see that the volume coefficient of diamagnetism is of the order of the ratio of the radius of the electron to the distance between adjacent atoms.

Since the volume coefficient of diamagnetism varies as l/d, and the atomic volume varies as d^3, we see that for metals of the same valency the diamagnetic coefficient should vary inversely as the cube root of the atomic volume.

Electron Theory of Solids

We shall now proceed to examine how atoms can be bound together not merely in twos or threes to form molecules, but in large numbers so as to form solids. We shall consider how such a collection of atoms is

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[31] *Comptes Rendus*, 158, p. 1895.
[32] *Phil. Mag.*, 40, p. 169.

held together and calculate some of its physical properties. We begin with the case when the atoms are all of one kind and when the solid is a crystal, so that it may be regarded as made up of units which are repetitions of each other. These units will be built up of atoms and electrons and the proportion between the number of atoms and the number of electrons will depend upon the valency of the element. Thus for the alkali metals there will be as many atoms as electrons, for the alkaline earths there will be two electrons for each atom, for trivalent metals like aluminum there will be three electrons for each atom and so on. Since the units completely fill space, they must be of the shape of one of the solids into which space may be divided, *i.e.*, the units must be parallelipeda, hexagonal prisms, rhombic dodecahedra or cubo-octahedra.

Let us take the case where the units are cubical. When a number of cubes are built up into a solid each corner of a cube will be the meeting place of eight cubes. Thus, if for purposes of calculation, we take the cube as our unit, and proceed to find the effect of one cube and take the sum of these effects for all the cubes into which the solid is divided, the effect due to an atom or electron at a corner will be counted eight times over. We may compensate for this by assigning to an atom or electron at the corner one-eighth of its normal charge. An atom or electron at the center of the face of a cube would be common to two cubes and so must be assigned half its normal charge, while an atom or electron at the middle point of a side of a cube will form a part of four cubes and so must be given one-quarter the normal charge.

Thus suppose the atom is at the centre of a cubical layer of electrons, then if the electrons are at the corners of the cube, both electrons and atoms will be arranged in simple cubical lattices, there will be as many electrons as atoms, the unit cell will be a cube with one-eighth of an electron at each corner and an atom at its centre. Suppose the electrons are at the middle points of the faces of the cube as well as at the corners, there will be four electrons for each atom so that the arrangement will be a possible one for a quadrivalent element. The symmetry of the arrangement shows that it corresponds to a crystal in the regular system. The cell in this case will be a cube with one-eighth of an electron at each corner and half an electron at the centre of each face.

Another quite symmetrical arrangement is when there is an electron at the corner of each cube and one at the middle point of each of its twelve sides; as each side is shared by four cubes the twelve electrons at the middle of the sides will only furnish three electrons to the cell, the one-eighth of an electron at each of the corners will contribute another, so that this arrangement would again be representative of an element in which there are four electrons per atom. The cell in this case will be a cube with one-eighth of an electron at each corner, one-quarter of an electron at the middle point of each side and an atom with a charge four at the centre.

The arrangement of the atoms in each of the preceding cases is that of a simple cubical lattice, the experiments of Sir William and Prof. W. L. Bragg on crystal structures have shown that one of the most frequent arrangements of the atoms is that of face-centred cubes. Here the atoms are at the corners and the centres of the faces of the cubes. If such a cube is taken as the unit cell, one-eighth of an atom must be placed at each corner and half an atom at the centre of each face: This makes each cell contain four atoms. If the atom is one of a monovalent element like lithium, the cell must contain four electrons. These electrons can be arranged with cubical symmetry in two ways—

1. By putting one-quarter of an electron at the middle point of each edge and one at the centre of the cube. This gives an arrangement where each atom has six electrons and each electron six atoms for its nearest neighbors. The atoms and electrons are arranged alternately at equal intervals along the lines of a simple cubical lattice.

This arrangement corresponds to that formed by Sir William and Prof. W. L. Bragg for the chlorides of the alkali metals.

2. Put one electron at the centre of four out of the eight cubes into which the unit cube is divided by planes bisecting the sides at right angles. The four cubes are to be chosen as follows: Take any one and put an electron at its centre, then electrons are to be put at the centres of the three cubes which have an edge but not a face in common with the cube originally chosen. When the cells are put together the same rule must be observed, any two small cubes which have a face in common must have an electron at the centre of one but not at the centre of the other. The four electrons in each cell

are at the corners of a regular tetrahedron. The distribution of the atoms and electrons is equivalent to one where each atom is at the centre of a regular tetrahedron of electrons and each electron at the centre of a regular tetrahedron of atoms.

Divalent Elements

If the atoms in the face-centred cell belong to a divalent element, since there are four atoms in the cell there must be eight electrons.

Two ways in which this may be done are as follows:

1. Fill up the four small cubes which were left empty on scheme 2 for the monovalent elements. Each atom will now have eight electrons as its nearest neighbors, the electrons being at the corners of a cube with the atom at its centre. The cubes surrounding two adjacent atoms have an edge in common and not a face as in the simple cubical arrangement for monovalent atoms.

2. Take the scheme 2 for four of the electrons and in addition place a quarter of an electron at the middle point of each of the twelve sides of the large cube and another electron at its centre.

Trivalent Atoms

When the atoms in the face-centred cube are trivalent there must be twelve electrons in the unit. We can find accommodation for these if we put one at the centre of each of eight small cubes into which the unit cube is divided, a quarter of one at the middle points of each of the twelve edges of the unit cube and another at the centre of this cube. This arrangement is equivalent to putting the atoms at the centres and the electrons at the corners of a series of rhombic dodecahedra filling space.

Tetravalent Element

The arrangement of the atoms in the diamond has been worked out by the Braggs. It is that shown in Fig. 41. The unit contains eight atoms distributed as follows: One-eighth at each of the corners of the unit, this accounts for one; one-half at the centre of each of the faces, this accounts for three; and four more at the centres of four of the eight cubes into which the unit cube is divided by planes bisecting the sides at right angles. The cubes to be occupied by the atoms are chosen by the same rule as that given for the arrangement of the electrons for the centre-faced arrangement for the monovalent element. As the unit contains eight carbon atoms and carbon is quadrivalent, there must be thirty-two electrons in the unit; these may be arranged as follows:

(*a*) At the middle points of the sides of the cubical unit; this accounts for three.

(*b*) At the centre of each of the faces of the eight small cubes; this accounts for twenty-four.

(*c*) At the centres of the four small cubes not occupied by the carbon atoms; this accounts for four.

(*d*) One at the centre of the large cube.

Röntgen-ray analysis has shown that for some elements the atoms are arranged at the corners and the centre of a cube. Taking this cube as the unit it contains two atoms; if the element is monovalent, it must contain two electrons. We cannot place these electrons so as to get complete cubical symmetry for one such unit; if, however, we group eight such units together, we get a larger cubical unit containing sixteen atoms, and it is possible to arrange sixteen electrons in this larger unit so as to get cubical symmetry. Thus we might put pairs of electrons along the diagonals of the eight cubes which go to make up the larger unit.

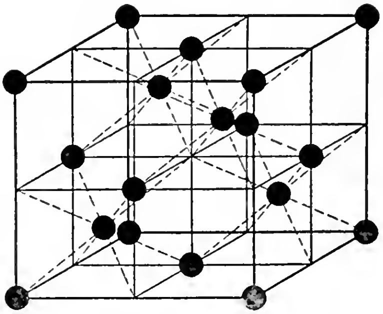

Fig. 41

If the atom were a divalent one we should have to accommodate four electrons in the original unit. This may be done by putting them at the centres of four out of the eight cubes into which the unit may be divided.

Hexagonal System

We have hitherto confined ourselves to the consideration of crystals in which the unit was a cube and the arrangement both of atoms and electrons completely symmetrical, so that the crystals would belong to the regular system. If our unit were a hexagonal prism, if, for instance, the electrons were at the corners and the atoms at the centres of hexagonal prisms, then since each corner is common to six prisms, we must, when calculating the electrical forces due to the unit, give to each electron at the corner one-sixth of its normal charge, the twelve electrons at the corners are thus equivalent to two electrons, so that the unit contains two electrons for each atom and would thus correspond to a divalent element.

The arrangement of electrons and atoms in the systems we have described have such regularity that the calculation of the properties of such an aggregate is easier than that of the properties of an aggregate of a small number of atoms in an individual molecule. For the electrons in one part of a molecule, for example, those at the ends of the two octets which form the oxygen molecule, are exposed to forces which are different from those acting on the electrons between the two oxygen atoms. The greater regularity in the arrangement of the electrons in the crystal more than compensates, as far as the mathematical difficulties are concerned, for the necessity of taking into account the effect of a much larger number of electrons and atoms than is necessary for the molecule.

I have in a paper published in the *Philosophical Magazine* (53, p. 721) calculated some of the properties of crystals when the atoms and electrons are arranged according to some of the schemes we have just been discussing. I shall describe the results of these investigations, beginning with the simplest case, where the atoms and electrons are both arranged in simple cubical lattices, where each atom may be regarded as the centre of a cube formed by eight electrons.

In the paper referred to, the stability of the system is investigated, and it is shown that if $2d$ is the distance between two atoms the arrangement will be stable, provided d is less than $c/1.69$ where c is the distance at which the force exerted by the positive nucleus on an electron changes from attraction to repulsion. As the distance between an atom and the nearest electron is $\sqrt{3d}$, *i.e.*, $1.72d$, we see that for the equilibrium to be stable, the shortest distance between an atom and an electron in the solid cannot exceed by more than a very small amount the distance of the electron from the centre of the atom when the element is in the gaseous state.

The system of electrons and atoms in the metal will have a very large number of periods of vibration, depending on the way the electrons are displaced relatively to each other and to the atoms; the highest frequency of these vibrations is when the electrons are not displaced relatively to each other, but only with respect to the atoms; this corresponds to the displacement which would be produced by light whose wavelength is long compared with the distance between two atoms. I find that this maximum frequency p, is given by the equation

$$mp^2 = .384\ ce^2/d^4 \qquad (45)$$

where m is the mass and e the charge on an electron.

If M is the mass of an atom and $\triangle$ the density of the solid, then since $8d^3$ is the volume of a cell, $1/8d^3$ is the number of cells in a cubic centimetre, hence

$$\frac{M}{8d^3} = \triangle \qquad (46)$$

so that equation (45) may be written as

$$mp^2 = .384\ e^2\frac{8\triangle}{M}\frac{c}{d} \qquad (47)$$

This type of vibration is the one that would be excited by waves such as those of visible or ultra-violet light whose wavelength is large compared with the distance between the atoms in the solid. We might therefore expect evidence of it in the behavior of monovalent metals when acted upon by light, the effect produced upon such metals would be greatest when the frequency of the incident light was that given by equation (45). An interesting case when the action of light on a metal is a maximum for light of a particular wavelength is what is known as the selective photoelectric effect.[33] This has been measured by Pohl and Pringsheim,[34] and in the following table, I give the comparison of the wavelength λ for which the selective photoelectric effect is a maximum for the monovalent metals sodium, potassium and rubidium as determined by Pohl and Pringsheim with the wavelengths calculated by equation (45) where c/d has been given the value 1.7, *i.e.*, on the supposition that the shortest distance between the atom and the electron in the metal is the same as that in the gas.

Metal	$\triangle$	$M/1.64\times10^{-24}$	λ Calculated	λ Observed
Sodium....	.971	23	3234	3400
Potassium.	.862	39	4457	4400
Rubidium.	1.532	85.45	4940	4800

It will be noticed that the agreement between the observed and calculated values is satisfactory.

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[33] *Hughes*, "Photoelectricity," Chap. 5.

[34] *Verh. d. Deutsch, Phys. Gesell.*, 13, p. 474 (1911).

It is interesting to compare the frequency of this type of vibration of the electrons in the solid, with P, that of the vibration of the electron in a gaseous atom, the latter can easily be proved to be given by the equation

$$mP^2 = e^2/c^3 \tag{48}$$

so we see from (4) if $1.7d = c$ and p is the frequency in the metal

$$p = 1.8P \tag{49}$$

thus the frequency in the metal is a little less than twice that in the gas, the values for the wavelength of the vibrations in the gaseous atom deduced from the table just given are for sodium 5800, and for potassium 7900.

The slowest vibrations of the electrons are when the displacement of adjacent electrons are in opposite directions. Thus suppose one of the lines of the electron lattice is vertical, then the slowest vibration of the electrons is when the electrons in any one line have all equal vertical displacements and the displacements of the electrons in the six vertical lines which are its nearest neighbors are equal in magnitude, but opposite in direction, to that in the line under consideration.

Compressibility of the Metals

We can calculate the potential energy due to the forces between the atoms and the electrons. I have given the calculations in a paper in the *Philosophical Magazine* (43, p. 721) and have shown that if the metal is supposed to be made up of cubical cells with an atom at the centre and one-eighth of an electron at each of its eight corners, each cell corresponding to an atom with its electron, the potential energy per cell is

$$-1.825\frac{e^2}{2d} \tag{50}$$

when $2d$ is a side of the cube. Thus, if there are N cells per unit volume, the potential energy per unit volume is

$$-1.825\frac{e^2}{2d}N \tag{51}$$

Now $N = 1/8d^3$, and if as before M is the mass of an atom and $\triangle$ the density of the metal

$$NM = \triangle \tag{52}$$

hence the potential energy per unit volume is equal to

$$-1.825\,e^2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \tag{53}$$

It is shown also that the work required to compress the cells so that the distance between two atoms is reduced from $2d$ to $2(d-\triangle d)$ is equal to

$$1.825\frac{Ne^2}{2d}\left(\frac{\triangle d}{d}\right)^2 \tag{54}$$

If dV is the diminution in a volume V due to this diminution in d

$$\frac{dV}{V} = 3\frac{\triangle d}{d} \tag{55}$$

hence the work required to compress the cells in unit volume is equal to

$$\frac{1.825}{9}\frac{N}{2d}e^2\left(\frac{dV}{V}\right)^2 = \frac{1.825}{9}e^2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}\left(\frac{dV}{V}\right)^2 \tag{56}$$

But if k is the bulk modulus, then this work is equal to

$$\frac{1}{2}k\left(\frac{dV}{V}\right)^2 \tag{57}$$

hence

$$k = \frac{3.65}{9}e^2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \tag{58}$$

The "compressibility" of the substance is equal to $1/k$.

We owe to Professor Richards invaluable determinations of the compressibility of the various elements. The following table contains the results of the comparison of his values of the compressibility with those calculated from equation (58).

Metal	$\triangle$	$M/1.64\times10^{-24}$	k Calculated	k Observed
Lithium	.534	7	$.14 \times 10^{12}$	$.114\times10^{12}$
Sodium	.971	23	$.068\times10^{12}$	$.065\times10^{12}$
Potassium	.862	37	$.03 \times 10^{12}$	$.032\times10^{12}$
Rubidium	1.532	85.5	$.022\times10^{12}$	$.025\times10^{12}$
Cæsium	1.87	132	$.016\times10^{12}$	$.016\times10^{12}$

Thus the results given by equation (58) are in close agreement with experiment.

If the atoms are in the gaseous state, the work required to change the radius of an atom from r to $r-\triangle r$ is equal to $\frac{1}{2}\,\frac{e^2}{c}\left(\frac{\triangle r}{r}\right)^2$.

Thus to produce the same percentage changes (45) in the sum of the volume of the atoms when in the gaseous state and (47) in the volume of the same number of atoms in the solid state requires the expenditure of amounts of work which are in the proportion of $\frac{1}{c}$ to $\frac{1.825}{d}$, or if $1.7d = c$, of 1 to 3.1. Thus the compressibility of the atoms in the solid state is about one-third of that in the gaseous.

The potential energy of a cell in the solid is equal to $-\frac{1.825\,e^2}{2d}$ or, since $\frac{1}{(2d)^3} = \triangle/M$, to

$-e^2\ 1.825\left(\frac{\triangle}{M}\right)^{\frac{1}{3}}$; if M' is the atomic weight of the element

$$M = 1.64 \times 10^{-24} \times M' \qquad (59)$$

hence the potential energy of the metal per cell is equal to

$$-e^2\ 1.5 \times 10^8 \left(\frac{\triangle}{M'}\right)^{\frac{1}{3}} \qquad (60)$$

This is equal to the energy acquired by the charge on an electron falling through a potential difference of

$$21.25 \times \left(\frac{\triangle}{M'}\right)^{\frac{1}{3}} \text{volts.} \qquad (61)$$

The values for the various alkaline metals are

Li = 9.25 volts
Na = 7.3
K = 6.36
Rb = 5.52
Cs = 5.100

The work which must be done to pull the cell from the metal and convert it into an atom of a monatomic gas is the difference between the potential energy in the cell and the potential energy of the gaseous atom; the latter when expressed in volts is for a monovalent element equal to the ionizing potential.

The potential energy per cell is equal to $-\frac{1}{2}\ (w_1 + w_2)$ where w_1 is the work required to remove a single electron from the metal and w_2 that required to remove a single atom. We have calculated $w_1 + w_2$, but not w_1 and w_2 individually. If the repulsion between the positive parts of two atoms was proportional to the inverse square of the distance, then w_1 would be equal to w_2, but if the repulsion is equal to $\frac{e^2}{r^2}\left(1 - \frac{cp}{r}\right)$, then w^2 will be greater than w_1, and w_1 will be less than $\frac{1}{2}\ (w_1 + w_2)$. Let $w_1 = \frac{\beta}{2}\ (w_1 + w_2)$ where β is a fraction, then the work required to remove any electron from the alkali metals will be β times the values given in the preceding tables. The contact difference of potential between two metals is equal to the difference in the amounts of work required to remove an electron from the two metals, thus the contact difference of potential between sodium and potassium would be $\beta\ (7.3 - 6.36) = .92\ \beta$ volts. The value found by experiment is .4 volt, hence $\beta = .44$, so that $w_1 = .44$ (potential energy per cell).

This gives the following values for the work required to tear an electron from the alkali metals.

Le = 4.07 volts
Na = 3.2
K = 2.79
Rb = 2.42
Cs = 2.24

The work required to tear an electron from sodium was estimated by Richardson from thermionic data as 2.6 volts, and from the photoelectric effect as 2.1 volts. The values given in the table represent the work required to remove an electron from the *body* of the metal; the atoms in the surface layers of the metal differ in energy from those in the interior, and an electron can escape from them with less expenditure of energy. As the values given in the table are less than half the amount of work required to remove both an electron and the positive part of an atom from the metal, the work required to remove an atom is greater than that required to remove an electron, so that when the metal is heated, the number of positive ions which come off will be small compared with the number of electrons.

The values given on page 848 for the compressibility are for a distribution of atoms and electrons such that the atoms are at the centres of cubes and the electrons at the corners.

When the atoms and electrons are arranged so that atoms and electrons occur alternately at equal intervals along the lines of a cubical lattice, we can show that the electrostatic potential energy for a volume of the metal containing N electrons and N atoms is

$$-1.77\frac{Ne^2}{d} \qquad (62)$$

where d is the shortest distance between an atom and an electron. If these N atoms and electrons make up unit volume, then if $\triangle$ is the density of the metal and M the mass of an atom, since a cube with side $2d$ contains four atoms

$$\frac{4M}{8d^3} = \triangle : NM = \triangle \cdot \qquad (63)$$
$$\frac{1}{d} = \left(\frac{2\triangle}{M}\right)^{\frac{1}{3}}$$

hence the electrostatic energy per unit volume is

$$-1.77\ e_2 2\frac{1}{3}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$$
$$= -2.2e_2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \qquad (64)$$

It follows from this that the bulk modulus is

$$\frac{2.2e_2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}, \qquad (65)$$

this is not very much more than half the value $\frac{3.65\ e_2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$ corresponding to the other distribution which we saw agreed very well with the experiment results; hence we conclude that the atoms and electrons cannot in the alkali metal be arranged so as to occur alternately at equal intervals along the lines of a cubical lattice.

For the arrangement where the atoms are arranged in face-centred cubes with electrons at the centres of four out of the eight smaller cubes into which the face-centred cube is divided, I find that the electrostatic potential energy for a volume containing N atoms and N electrons is

$$-3.50\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \qquad (66)$$

so that k, the bulk modulus, is equal to

$$\frac{-3.50}{9}e_2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \qquad (67)$$

this differs by less than 5 per cent from the value given by equation (58), and would agree within the errors of experiments with the values found by Richards.

When the arrangement of the atoms of a monovalent element is that of the body-centred cube and the electrons are placed two by two along the diagonals of eight such cubes taken as a single unit, Miss Woodward finds

$$k=\frac{3.2}{9}e_2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \qquad (68)$$

This would give values for k appreciably smaller than those found by experiment. The arrangement of the electrons was assumed to be as follows: Two electrons were placed inside each cube on a diagonal, one on one side of the centre, the other on the other, midway between the centre of the cube and the ends of the diagonal. The diagonals along which the electrons are placed are chosen so that in a cube built up of eight such small cubes no two of the diagonals in any four whose centres are in one plane are parallel or intersect. The diagonals in two cubes which have a corner but neither an edge nor a face in common are to be parallel. This arrangement is equivalent to arranging the atoms and electrons alternately at equal intervals along lines whose directions are parallel to the four diagonals of the cube.

The Energy and Compressibility of Divalent Elements

We shall further test the electron theory of solids by calculating the compressibility of a divalent element. Calcium crystallizes in the regular system and the arrangement of the atoms has been shown by X-ray analysis to be that of the face-centred cube. Taking such a cube as the unit, it contains four calcium atoms; since calcium is divalent, if there are four atoms there must be eight electrons. The most symmetrical way of arranging these is to place one at the centre of each of the eight small cubes into which the unit cube is divided by planes bisecting its sides at right angles.

Taking this arrangement, I find that the electrostatic potential energy of a calcium atom is, if $2d$ is a side of the unit cube,

$$-\frac{e^2}{d}5.33 \qquad (69)$$

while that of an electron is equal to

$$-\frac{e^2}{d}1.8 \qquad (70)$$

Hence the electrostatic potential energy of one atom and two electrons is

$$-\frac{e^2}{d}8.93 \qquad (71)$$

The total actual potential energy, *i.e.*, the potential energy when we take into account the effect of the forces varying inversely as the cube of the distance is one-half of this, *i.e.*

$$-\frac{e^2}{d}\,4.46 \qquad (72)$$

Since the cube whose volume is $8d^3$ contains four atoms

$$\frac{4M}{8d^3}=\triangle \qquad (73)$$

where M is the mass of an atom and $\triangle$ the density of the metal; hence the energy per unit volume is equal to

$$-e^2\ 5.61\times\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \qquad (74)$$

The bulk modulus k is equal to

$$e^2\frac{11.2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \qquad (75)$$

for calcium $\triangle=1.55$ and $M=40\times1.64\times10^{-24}$, hence k for calcium $=.192\times10^{12}$. The compressibility which is the reciprocal of k is 5.2×10^{-12}; the value found by Richards is 5.5×10^{-12}, so that the agreement between the observed and calculated values is quite satisfactory.

The potential energy for an atom and two electrons is that corresponding to the fall of an electron through twenty-two volts.

The Compressibility of a Trivalent Element

Aluminum is a trivalent element crystallizing in the regular system. The arrangement of the atom has been shown to be that of a face-centred cube. Taking this cube as the unit it contains four atoms; it must, therefore, since aluminum is trivalent, contain twelve electrons. If we place electrons at the middle points of the sides, at the centres of each of the eight cubes into which the unit cube is divided by bisecting planes and one at the centre of the cube, we get a symmetrical distribution of these twelve electrons. This distribution is the same as if each atom were placed at the centre of a rhombic dodecahedron and the electrons at the corners of the dodecahedron. Since four planes meet at some of the corners while only three meet at others, we see that the electrons will be divided into two groups.

For this arrangement I find that the electrostatic potential energy of the atom, with its triple charge of electricity, is equal to

$$-e^2\frac{10.6}{d} \tag{76}$$

where $2d$ is the side of the face-centred cube and e the charge on an electron.

For an electron at a corner of the dodecahedron where four planes meet, the potential energy is

$$-e^2\frac{.05}{d} \tag{77}$$

and for an electron at a corner where three planes meet

$$-e^2\frac{1.75}{d} \tag{78}$$

Each atom is associated with one electron of the first type and two of the second, hence the electrostatic potential energy of this system is $-e^2\dfrac{14.25}{d}$ and the total potential energy $-e^2\dfrac{7.12}{d}$.

Now

$$\frac{1}{d}=\left(\frac{2\triangle}{M}\right)^{\frac{1}{3}} \tag{79}$$

hence k the bulk modulus is given by the equation

$$k=\frac{17.8}{9}e^2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}} \tag{80}$$

for aluminum $\triangle=2.65$, $M=27\times1.64\times10^{-24}$; hence $k=1.08\times10^{12}$, the value found by experiment is $.78\times10^{12}$.

Compressibility of the Diamond

In the diamond we have a quadrivalent element crystallizing in the regular system. The arrangement of the carbon atoms in the diamond has been shown by Sir W. H. Bragg and Prof. W. L. Bragg to be given by the following scheme. The atoms occupy

(*a*) the corners of a cube;
(*b*) the centres of its faces;
(*c*) four of the centres of the eight cubes into which the large cube is divided by planes bisecting its sides at right angles.

We shall take this cube as our unit; it contains eight carbon atoms. Since carbon is quadrivalent, it must contain thirty-two electrons; these electrons will be situated

(*a*) at the middle points of the edges of the cubical unit; this accounts for three;
(*b*) at the centres of each of the faces of the eight small cubes; this accounts for twenty-four;
(*c*) at the centres of the four small cubes not occupied by the carbon atoms; this accounts for four;
(*d*) one at the centre of the large cube.

Making use of this unit, we can calculate the electrostatic potential energy due to the charges on the atoms and electrons. Let E be the charge on a carbon atom, e that on an electron.

The electrostatic potential energy of a carbon atom

$$\frac{1}{2}E\left(\frac{\Sigma e}{r'}-\frac{\Sigma E}{r}\right) \tag{81}$$

I find to be equal to

$$\frac{1}{2}\frac{E}{d}(149.346e-35.13E), \tag{82}$$

where $2d$ is the side of a unit cube. Since $E=4e$, this reduces to

$$17.65\frac{e^2}{d}. \tag{83}$$

The electrostatic potential energy of an electron I find to be

$$\frac{1}{2}\frac{e}{d}\left\{\frac{E}{4}149.346-147.59e\right\} \tag{84}$$
$$=\frac{1}{2}\frac{e^2}{d}1.75.$$

Hence the electrostatic potential energy for the atom and its four associated electrons is $21.15\frac{e^2}{d}$.

Since there are eight atoms in the cube whose edge is $2d$, if $\triangle$ is the density of the diamond and M the mass of a carbon atom,

$$\frac{8M}{8d^3} = \triangle \tag{85}$$

or

$$\frac{1}{d} = \left(\frac{\triangle}{M}\right)^{\frac{1}{3}}. \tag{86}$$

Thus the electrostatic potential energy per one atom and four electrons is

$$21.15\, e^2\left(\frac{\triangle}{M}\right)^{\frac{1}{3}}, \tag{87}$$

and the energy per unit volume is

$$21.15\, e^2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}. \tag{88}$$

Hence k, the bulk modulus of the diamond, is given by the equation

$$k = \frac{21.15}{9} e^2\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}; \tag{89}$$

for the diamond $\triangle = 3.52$, $M = 12 \times 1.64 \times 10^{-24}$; hence $k = 5.6 \times 10^{12}$, $1/k = .178 \times 10^{-12}$.

This value for $1/k$ is much less than that, $.5 \times 10^{-12}$, found by Richards. It is, however, in close agreement with $.16 \times 10^{-12}$, the value recently found by Adams.[35]

The properties of solids formed by elements whose atoms have more than four disposable electrons are quite different from those of solids formed by the elements with one, two or three disposable electrons. The latter are, with the exception of boron, metallic and good conductors of electricity and heat. The former, for instance sulphur and phosphorus, are insulators. Not only do they insulate in the solid state, but they do so after they are fused. They differ in this respect from solid salts which, though they may insulate when in the solid state, generally conduct when melted. This suggests that in the salts there are positively and negatively electrified systems which are fixed when the substance is in the solid state, but can move about when it is liquefied. In such elements as sulphur or phosphorus there does not seem to be any evidence of existence of anything but neutral systems; in other words, the solid may be regarded as built up of units, each of which contains as much positive as negative electricity. It is noteworthy that, according to the Electron Theory of Chemical Combination, two similar atoms, if they have each more than four disposable electrons, like the atoms of sulphur and phosphorus, can combine and form a saturated molecule, which is electrically neutral.

Thus we are led to distinguish three types of solids:

(*a*) A type where the atoms are arranged in lattices, and the electrons in other lattices coordinated with the atomic ones. In this type each electron has no closer connection with a particular atom than it has with several others. Thus, for example, when the electrons form a simple cubical lattice with the atoms at the centres of the cubes, each electron has eight atoms as equally near neighbors; so that an electron is not bound to a particular atom. This type includes the metals; it also includes boron and carbon in the form of diamond, which are insulators.

(*b*) A type represented by the salts; here the atoms are again arranged in lattices, but each electron has much closer relation with one particular atom than it has with any other. Thus to take the case of NaCl, where the Braggs have shown the atoms to be arranged according to the following scheme:

Na	Cl	Na	Cl
Cl	Na	Cl	Na
Na	Cl	Na	Cl

We suppose that each sodium atom has lost an electron, while each chlorine atom has gained one; thus each chlorine atom has eight electrons around it, and each electron is much more closely bound to one particular chlorine atom than to any other. It is so closely associated that it is not dissociated from its partner in either the solid or liquid state of the substance. Thus the chlorine system always has a negative charge, the sodium one a positive. These atoms do not move when the substance is in a solid state, though they may do so when it is liquefied.

If the distance of the electrons from the chlorine atoms were to increase until it was not far from half the distance between the sodium and chlorine nuclei, this type would approximate to type (*a*).

(*c*) A type where the lattices are built up of units which are not electrified; such units are probably molecules containing two or more atoms, though in certain cases they may be single atoms. The characteristic of the type is that each unit has sufficient elec-

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[35] *Washington Acad. Sc.*, 11, p. 45 (1921).

trons bound to it to make it electrically neutral, and that each electron remains attached to a particular atom. Thus where an electric force acts on the system there is no tendency to make the unit move in one direction rather than the opposite, so that the substance cannot conduct electricity.

There is something anomalous about the compressibility of silicon; the arrangement of its atoms as determined by X-ray analysis is the same as that of the diamond, while its atomic volume is 2.7 times greater. We might therefore expect that its compressibility would be (2.7), or 3.8 times that of the diamond. Its compressibility, however, as determined by Richards, is only $.16\times10^{12}$, which is practically the same as the revised value for the diamond. In silicon, however, there are two layers of electrons so that when the four electrons in the outer layer have been distributed to form the lattice, a layer of eight will remain surrounding the positive part of the atom. The compression of the silicon may involve not merely the closer approach of the positive parts of the silicon atoms, but also a closer approach to the central atom of the layer of eight electrons which surround it. The work required to do this would tend to make the compressibility less than for a substance like carbon, which after its outer layer has been distributed, has no inner layer left to compress.

The case may be compared with that of a chloride of an alkali metal, say LiCl. In the lattice formed by the atoms each chlorine atom is surrounded by a layer of eight electrons. The compressibility of the salt has been determined by Richards and it is much less than the value calculated on the supposition that the chlorine ion with its octet of electrons round a positive charge of seven units can be treated as a negative charge of one unit at the centre of the chlorine atom. The compression of the octet round the chlorine atom has also to be taken into account. Miss Woodward has done this recently and finds that the calculated values are in fair agreement with those determined by experiment.

A similar argument applies to the elements copper, silver and gold, which are far less compressible after allowing for the difference in the atomic volume than they would be if they followed the same law as the other monovalent elements, the alkali metals. The heavier alkali metals have also inner layers, but the atomic volume of these is so great that the compression of these layers does not come nearly so much into play as in gold and silver, which have much smaller atomic volumes.

TABLE VIII

Potential Energy per Atom with Its Associated Electrons

Monovalent Elements	
CUBICAL	$\frac{3.65\,e^2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$
FACE-CENTRED CUBE:	
Electrons at middle points of edges and centre of cube	$\frac{2.2\,e^2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$
Electrons at centres of four constituent cubes	$\frac{3.5\,e^2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$
BODY-CENTRED CUBE	$\frac{3.2\,e^2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$
Divalent Elements	
FACE-CENTRED CUBE:	
Electrons at centres of eight constituent cubes	$\frac{11.2\,e^2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$
Electrons at centres of edges and four constituent cubes	$\frac{7.75\,e^2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$
Trivalent Elements	
FACE-CENTRED CUBE:	
Electrons at middle points of edges and centre of cube and at centres of four constituent cubes	$\frac{18\,e^2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$
Quadrivalent Elements	
FACE-CENTRED CUBE and at:	
Centres of four constituent cubes. Electrons, centres of edges, centres of faces of constituent cubes and at centres of four of these cubes	$\frac{21.15\,e^2}{9}\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$

We may sum up the results of the preceding investigation of the compressibility of solids as follows:

The compressibility is equal to $C\left(\frac{\triangle}{M}\right)^{\frac{4}{3}}$,

where C is a quantity depending on the valency of the element and the form in which it crystallizes; $\triangle$ is the density of the solid and M the mass of an atom of the element.

The potential energy of an atom with its associated electrons is equal to

$$-\frac{4.5}{c}\left(\frac{\triangle}{M}\right)^{\frac{1}{3}} \tag{90}$$

Table VIII contains a summary of the preceding results.

Surface Tension

The preceding expression represents the energy of an atom in the mass of the metal, for one on the surface it requires modification. Thus if P is an atom or electron part of its potential energy depends on the atoms and electrons above a horizontal plane through P. If the metal is broken so that this plane becomes a surface of the metal, the atoms and electrons above P will no longer affect the potential energy so that this will be changed. We can find an approximation to the amount of this change in the following way: Let us take a crystal of a monovalent element and suppose that the atoms and electrons are arranged in the plane of the surface according to the scheme when the atoms are at the corners and centres of the faces of a cube and the electrons at the middle points of the sides and the centre of the cube. This is the more convenient arrangement to take, since the atoms are present in equal numbers in the plane, so that the total electric charge upon it is zero. With this arrangement I find that the contribution of the atoms and electrons above P to the potential energy of the system consisting of P and an electron is $-.075\frac{e^2}{d}$, where d is the distance between an atom and the nearest electron. We saw that in this case for an atom and electron in the interior the energy is $-1.77\ \frac{e^2}{d}$. Thus the potential energy S of the atom and electron in the surfaces exceeds I, the potential energy in the interior by $\frac{.075}{1.77}\ I = 0.42\ I$. The surface tension arises from the excess of the potential energy of the atoms in the surface over those in the interior and is equal to the excess for one atom multiplied by the number of atoms in unit area of the surface. Let us apply this to find the surface tension of sodium. The energy of an atom of sodium not on the surface is equal to that gained by an electron falling through 7.2 volts, *i.e.*, $7.2\times 1.6\times 10^{-12}$ ergs. The distance between two sodium atoms is equal to 3.37×10^{-8}, hence the number of sodium atoms per square centimetre is $10^{16}/11.35$. Thus the surface tension of sodium is

$$.042\times 7.2\times 1.6\times 10^{4}/11.35 \qquad (91)$$
$$=432 \text{ ergs/cm.}^2$$

The value given in the tables for molten sodium is 500, so that the calculated and the observed value are of the same order of magnitude. The calculation is only a rough approximation as we have neglected the effect of temperature and supposed that the distance between the sodium atoms is the same on the surface as in the interior. The increase in the potential energy at a surface will depend upon the orientation of the surface. Thus if the face of the sodium is a plane parallel to the diagonal plane of the cube instead of the plane parallel to one of its faces, I find that the potential energy of an atom and electron at the surface will be greater than if they were in the interior by .067 I instead of .0423 I as in the former case. In this plane the number of atoms per unit area is only $1/\sqrt{2}$ that in the former case, thus the surface tension in this plane will be to that in a plane parallel to a face of the cube in the proportion of 47.3 to 42. The atoms in this plane having greater potential energy than those in a plane parallel to the faces of the cube will develop a greater amount of heat when they enter into chemical combination. I find that for a gram molecule of sodium the difference would be about 10,000 calories. Thus chemical action would be more likely to go on at these faces than at the natural cleavage faces of the crystal; the photoelectric emission of electrons would also be greater.

Communication of a Charge from Gaseous Ions to the Electrodes

The preceding values have an important bearing on the transmission of electric charges from gaseous ions to metallic electrodes.

Consider first the case of a positively charged ion. If this is to give up the charge to the electrode and escape as an uncharged atom or molecule, an electron must come from the metal, and be received by the ion. Let the work required to abstract the electron from the metal be V_m and let the ionizing potential of the gas be V_g, there the work required to discharge the ion is $V_m - V_g$. If V_m is greater than V_g it will require an expenditure of work to discharge the ion, the ion will not give up its charge, *i.e.*, there will be no continuous current through the gas unless the external potential difference is greater than $V_m - V_g$.

Now take the case of a negatively electrified ion giving up its charge to the anode; here an electron has to be taken from the ion and given up to the anode; to remove the electron requires an amount of energy equal to V_1, where V_1 is the work required to move an electron from the negatively charged ion, it will be less than the ionizing potential. On the other hand, work equal to V_m is gained when the electron goes into the metal thus to effect the transference, work equal to $V_1 - V_m$ must be done, so there must be an external potential difference greater than $V_1 - V_m$ to keep up the current.

It would seem as if experiments on the potential required to effect the passage of electricity from the gas to the metal ought to give us the means of finding V_g and V_1, quantities which are of fundamental importance in the energetics of chemical combination. To illustrate the kind of effects we are considering, let us take the case of ionized mercury vapor, the ionizing potential of mercury vapor is about 10 volts; I cannot find any direct measurements of the work required to extract an electron from liquid mercury, but inasmuch as mercury gives off electrons when exposed to light whose wavelength is not less than 2000, it can not be greater than about five volts; thus V_m is much less than V_g; thus a positively charged mercury atom could give up its charge to a liquid surface of mercury without the aid of an external potential difference. Unless, however, the work required to extract an electron from a negatively electrified mercury atom is less than half that required to extract it from a neutral one, V_1 would be greater than V_m and it would require an external electromotive force to make negatively electrified mercury atoms give up their charge to a mercury surface. Both the gas and the electrode can be varied in these experiments; thus if the gas were a strongly electronegative one, like chlorine, we should expect V_1 to be greater than V_m for a metal like sodium for which Richardson's value is 2.6 volts; if so, it would require an external electric force to make negative chlorine ions discharge to sodium and get free. The chlorine ion would cling to the sodium and combine with it, thus with chlorine ions and an electropositive metal as electrode, the anode would be more likely to be attacked by the chlorine than the cathode. To liberate the electron from the chlorine and get a neutral chlorine atom would require a potential difference at the anode equal to $V_1 - V_m$. At the cathode a positively electrified chlorine atom might not merely get neutralized by receiving one electron, but if V_1 were greater than V_m, work would be gained by the chlorine atom receiving a second electron from the metal. When an electron falls into an atom, light is emitted; the frequency of the light depending on the amount of loss of potential energy caused by the falling in of the atom, or what is the same thing, by the work required to eject the electron again. This work where a positively charged chlorine atom receives one electron and becomes neutral is measured by the ionizing potential of the chlorine atom; when a neutral atom receives an additional electron it is measured by V_1. Thus, whenever, at the surface, say of an alkali metal, the transference of electrons from the metal to, say, chlorine atoms, is going on, light will be emitted; this light will fall upon the metal, and as these metals give large photoelectric effects, it may cause them to emit electrons. As the light is emitted quite close to the surface of the metal it is quite likely that the intensity at the surface may be sufficient to produce measurable effects though the intensity of the light may be much too faint to be detected at distances large compared with the radius of an atom.

Intermetallic Compounds

The expression we have found for the potential energy of a solid has an important application to the theory of intermetallic compounds and alloys. Take the case of two metals, A and B, when they are apart they consist of lattices of atoms and electrons, and as we have seen may be regarded as built up of units, each unit containing a certain number of atoms, together with the appropriate number of electrons. Thus if the metal were monovalent there would be as many electrons as atoms; if it were divalent there would be twice as many, and so on. Suppose now that the metals were mixed under conditions which permitted free movement of the atoms and electrons. Then in the mixture in addition to the units consisting wholly of A or of B atoms, we may have units containing both A and B atoms. Thus to take a definite case, let A be sodium and B potassium, the unit might be a cube of side $2d$, built up of eight cubes; at the centres of these, atoms of sodium and potassium might be placed alternately, the electrons would be at the corners, the centres of the faces and the centres of the edges, and at the centre of the large cube. Such a unit would certainly be formed at low temperatures if its potential energy were less than that due to four units of sodium and four of potassium when these metals were separated. Again we might have a cubical unit with the potassium atoms at the corners and the sodium atoms at the centres of the faces, in this unit there would be three sodium to one potassium atom. There are many other possible units with different proportions of sodium and potassium atoms. Whether such units will be formed or not is a question of the relation between the potential energy of such a unit and the potential energy of the atoms it contains when arranged so that the units contain only one kind of atom. The point I wish to emphasize is that the conditions which determine the formation of these metallic compounds are of quite a different kind from those which determine the formation of gaseous compounds containing one or more electronegative constituents. With these it is the valency conditions, such as may be expressed by the formation of octets, which govern the type of admissible compound; with the metals, on the other hand, the formation or not of a compound is determined by the potential energy possessed, by a unit of the lattice system formed by the compound. As this potential energy depends on the number of electrons as well as upon the number of atoms in the unit, and as the number of electrons depends upon the valencies of the atoms, valency will have an influence upon the type of compound, but of a different character to that exerted in compounds between metals and electronegative elements. From these considerations we should expect that the structure of intermetallic compounds would not conform to the condition of valency as ordinarily understood. We find, for example, many stable compounds in which two atoms of a bivalent metal are combined with one atom of a univalent one, *e.g.*, $NaCd_2$, KHg_2, $CuMg_2$, a proportion inconsistent with the usual conception of valency, but one which would be satisfied by a very simple form of unit cell. Thus if the divalent atoms were at the corners of a hexagonal prism and the monovalent atom at the centre, while the electrons were placed at the centres of side faces of the prism and two along the axis on either side of the monovalent atom, we have a unit containing two divalent atoms, one monovalent atom and five electrons.

Mixed Crystals and Intermetallic Compounds

Metallurgists distinguish between two types of combination between metals. The one type called intermetallic compounds consists of alloys of a composition at which on a graph representing the relation between percentage composition and some physical property, such as electrical conductivity, shows a well-marked maximum or minimum. These points in general correspond to alloys in which the proposition between the numbers of atoms of the two metals are expressed by simple ratios. Alloys of other composition represented by the regions between the maxima and minima are supposed to be in a state which is sometimes described as mixed crystals and sometimes as solid solutions.

Let us consider the question of the combination of two metals *A* and *B* from the point of view of the electron theory of solids. There are several possibilities, the alloy might be a mechanical mixture of *A* and *B*; by this we mean that the atoms of *A* and *B* are respectively arranged in their own space lattices, and that there are no composite space lattices made up of atoms of *A* and *B* arranged in regular sequence. Another alternative is that the atoms should be arranged in composite space lattices, the atoms along the lines of the lattices consisting partly of *A* atoms and partly of *B*. Here there are again several possibilities, for with a fixed proportion between the number of *A* atoms and the number of *B* there are many different composite lattices possible. Thus, for example, if there are three *A* atoms for one of *B*, we might in two dimensional lattices have the spacings

I.

a a a a a a a a a
a b a b a b a b a
a a a a a a a a a
a b a b a b a b a

or

II.

a a a b a a a b a a a b a a a
a b a a a b a a a b a a a b a
a a a b a a a b a a a b a a a

or

III.

a a b a a b a a b a a b a a b
a a a a a b a a a a a a b a a a
a a b a a b a a b a a b a a b

Thus the alloy might consist either of one kind of lattice or a mechanical mixture of a number of different kinds. If the atoms have been in a condition in which they could diffuse freely, *e.g.*, if the alloy were stirred for a long time when the melt was liquid, the arrangement would be that corresponding to minimum potential energy, remembering that when there is a mechanical mixture of different phases we must take into account the energy due to surface tension. When there is a well-marked minimum in the potential energy for one arrangement of the atoms, we should expect that the alloy would be homogeneous and represented by a single lattice corresponding to this arrangement. If, on the other hand, there are several arrangements which differ but little from each other in potential energy we might expect to find all these arrangements present in the alloy in proportions which would vary with the temperature. When the alloy is homogeneous and the arrangement of atoms and electrons capable of being represented by a single lattice, it corresponds in my view to an intermetallic compound. When, however, there are several different arrangements mixed together, it corresponds to a solid solution.

When the atoms of *A* and *B* carry the same charge of electricity, then if *A* is greatly in excess we should expect the *B* atoms to occupy positions along a space lattice that differed but little from that for pure *A*. When, however, the number of the *B* atoms increase beyond a certain proportion, there will probably be large modifications in the space lattice for the mixture and possibly the formation of one of quite a different character. The probability of a new type of space lattice will be much increased if *B* and *A* carry different electrical charges, *i.e.*, have different valencies.

Let us consider from this point of view the changes we might expect in the properties of a mixture of two metals, *A*, *B*, starting from pure *A* and ending with pure *B*.

When *A* is greatly in excess, the formation of those compounds which contain a comparatively large proportion of *A* in comparison with *B* will, in accordance with the principles of mass action, be promoted, and the mixture will consist of free *A*, little or no free *B*, and a number of compounds, the majority of which contain an excess of *A* over *B*. As the proportion of *B* increases the amount of free *A* diminishes and the proportion between the amounts of different types of compounds changes, the change being mainly at the expense of those which contain a large number of *A* atoms. When the mixture is such that the proportion between *A* and *B* is that of a possible compound, if that compound is one which has markedly less potential energy than its constituents, the whole mass of metal at low temperatures at any rate may practically consist of this compound. It need not, however, do so in all cases; there may be a certain amount of dissociation of the compound depending upon the temperature. Again, if there is another compound with very small potential energy, some of it is pretty sure to be formed, so that the mixture may not be quite homogeneous even when the proportions are those of a possible compound. When the mixture consists almost entirely of one compound, its constitution is identical in many respects with that of a simple metal. All the units of which it is built up are of one kind, and that kind an arrangement of atoms and electrons, which when the units are united give, as in the cases of metals, a system of lattices for atoms and electrons. Any general property possessed by all metals would, we should expect, be possessed by this compound. In particular the conduction of electricity through the compound would take place by the same mechanism as through metals. Now one peculiarity of the conduction of electricity through metals is that the temperature coefficient of the electrical resistance is much the same for all metals, hence we should expect that the temperature coefficient of an intermetallic compound would be about that of the pure metals. There seems to be very considerable evidence[36] that this is approximately true.

The temperature coefficient of the electrical resistance when the mixture of the two metals contains several compounds is often very much smaller than that for pure metals; in fact, it is even sometimes of opposite sign. When there are several different components the effect of a rise in temperature will be an increase in the dissociation and hence an alteration in the proportion of the amount of different compounds present in the alloy. The more complicated compounds will be split up by the rise in temperature and the proportion of simpler ones increased. As the lattices formed by the complex compounds are more intricate than those of the simpler ones, we should expect their electrical resistance to be greater so that when some of these are split up owing to the rise in temperature there will be a tendency to reduce the resistance. Thus in a mixture of this kind there is, in addition to the normal effect which makes the resistance increase, an effect tending to make the resistance fall when the temperature rises; this will diminish the temperature coefficient of the resistance.

Let us now consider the changes in the elastic properties produced by the formation

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[36] "Desch, Intermetallic Compounds," p. 52.

of these intermetallic compounds. We have seen that in the solid state the potential energy of an atom and its associated electrons is equal to

$$-4.5\frac{N_A}{k_A} \qquad (92)$$

when k_A is the bulk modulus and N_A the number of atoms in unit volume for the element A, since $N_A = \Delta_A/M_A$ where Δ_A is the density of A and M_A the mass of its atom, the potential energy per atom may be written as

$$-4.5\,k_A\frac{M_A}{\Delta_A} \qquad (93)$$

Thus the potential energy of n atoms of a metal A and m of a metal B before they combine is equal to

$$-4.5\left(k_A\frac{nM_A}{\Delta_B}+k_B\frac{mM_B}{\Delta_B}\right) \qquad (94)$$

If these unite to form the compound A_nB_m, the potential energy per molecule of this compound is

$$-4.5\frac{k_{nm}}{\Delta_{nm}}(nM_A+mM_B) \qquad (95)$$

Where k_{nm} is the bulk modulus of the compound and Δ_{nm} its density, thus by the formation of the compound, the diminution of potential energy per molecule of the compound formed is

$$4.5\left\{\frac{k_{mn}}{\Delta_{mn}}(nM_A+nM_B)-\left(\frac{nk_AM_A}{\Delta_A}+\frac{mk_BM_B}{\Delta_B}\right)\right\} \qquad (96)$$

and this must be equal to the heat of formation per molecule of the compound at zero absolute temperature. Thus from the compressibilities of the compound and those of its constituents we can calculate the heat of formation of the compound.

Again

$$\frac{nk_AM_A}{\Delta_A}+m\frac{k_BM_B}{\Delta_B}=K\left(\frac{nM_A}{\Delta_A}+\frac{mM_B}{\Delta_B}\right) \qquad (97)$$

and

$$\frac{nM_A}{\Delta_A}+\frac{mM_B}{\Delta_B}=\frac{nM_A+mM_B}{\Delta} \qquad (98)$$

Where K is the bulk modulus and Δ the density of the mixture, calculated on the assumption that A and B exert no influence on each other, hence the diminution in potential energy due to the formation of the compound may be written in the form

$$4.5\,(nM_A+mM_B)\left\{\frac{k_{mn}}{\Delta_{mn}}-\frac{K}{\Delta}\right\} \qquad (99)$$

Now the compound will not be formed unless the potential energy diminishes, hence

$$\frac{k_{mn}}{\Delta_{mn}}-\frac{K}{\Delta}$$

must be positive, or if, as is generally the case, Δ_{mn} is very nearly equal to Δ, k_{mn} must be greater than K; in other words, the compound must be less compressible than a mechanical mixture of the metals. It is a general rule that the "hardness" of an alloy is greater than we should expect from its composition, and though hardness is not the same thing as the reciprocal of the compressibility yet some of the tests used to measure the hardness, *e.g.*, the indentation produced by a loaded ball, seem almost more a test of compressibility, the result that combination diminishes the compressibility seems to be indicated.

(Concluded)

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Busbars

Heavy Alternating-current Buses for Furnaces and Synchronous Converters. Yardley, J. L. McK.
Blast Fur. & St. Pl., Sept., 1923; v. 11, pp. 492-494.
(Discusses difficulties due to magnetic effects. Serial.)

Magneto-mechanical Loads on Bus Supports. Robinson, Lloyd N.
A.I.E.E. Jour., Oct., 1923; v. 42, pp. 1063-1067.
(Shows the importance of giving more attention to strength of bus supports and presents methods of calculating stresses on them.)

Carrier-current Communication

Radio Has Been Adopted for Emergency Communication. D'Alton, F. K.
Elec. News, Oct. 1, 1923; v. 32, pp. 57-60.
(General description of the "guided wave" system of the Hydroelectric Power Commission of Ontario.)

Telephoning Over Power Lines.
Elec. Rwy. Jour., Sept. 1, 1923; v. 62, p. 336.
(Brief account of the installation on the lines of the Consumers Power Co., Michigan.)

Cars, Electric

New Forms of Transportation. Potter, W. B., and Andrews, H. L.
Elec. Trac., Sept., 1923; v. 19, pp. 506-508.
("How buses and trackless trolleys should be used in order that transportation shall be most economical.")

Trolley Buses and Flexible Vehicles for Street Railway Service. Kennedy, William P.
Soc. Auto. Engrs. Jour., Sept., 1923; v. 13, pp. 179-195.
(Surveys the field of application of the trolley bus and describes and illustrates several European and American types.)

Circuit Breakers

High-tension Oil Circuit Breakers. Delling, W. (In German.)
Elektro-Jour., Aug.-Sept., 1923; v. 3, pp. 174-179.
(Illustrated description of breakers and explanation of their operating characteristics.)

Incorporating Series Trip Coil Inside Circuit Breakers.
Elec. Wld., Sept. 29, 1923; v. 82, pp. 660-661.
(Method used by the Tennessee Electric Power Company.)

Welding Current of Oil Switches. Metz, G. L. E
Elec. Rev. (London), Sept. 7, 1923; v. 93, pp. 344-345.

Coal Storage

Storage of Bituminous Coal.
Power, Sept. 25, 1923; v. 58, pp. 513-514.

Condensers, Static

Dielectric Stresses in Static Condensers for Power-factor Correction. Marbury, R. E., and Atherton, A. L.
Elec. Jour., Sept., 1923; v. 20, pp. 334-337.

Electric Conductors

Why Use Weatherproof Line Wire? Lindsay, S. C.
Elec. Wld., Sept. 22, 1923; v. 82, pp. 609-610.
(Brief article including a summary of tests on 42 samples of weatherproof line wire.)

Electric Control Systems

Electrical Control for a Hot Strip Mill at the West Leechburg Steel Company. Wohlgemuth, M. J.
Elec. Jour., Sept., 1923; v. 20, pp. 322-325.

Foot Control for Main Reversing Mill Motors. Wright, R. H.
Elec. Jour., Sept., 1923; v. 20, pp. 320-321.
(A companion article entitled: "Foot Control at Steelton" follows on pp. 321-322.)

Supervisory Systems for Remote Control. Stewart, C. E., and Field, J. C.
Elec. Wld., Sept. 29, 1923; v. 82, pp. 655-659.
(Illustrated description of apparatus and methods for remote control of power networks.)

Electric Distribution

Underfloor Duct System.
Elec. Wld., Sept. 22, 1923; v. 82, pp. 595-598.
(Describes the underfloor system of distribution for large buildings.)

Electric Drive

Choosing Proper Type of Motor. Johnson, C. N.
Iron Tr., Sept. 20, 1923; v. 73, pp. 812-813.
(Tells of factors to be considered in choosing open, semi-enclosed, or enclosed motors for electric drive in general.)

Electric Drive—Blowers

Electric Drive for Centrifugal Fans, Blowers and Propeller Fans. Fox, Gordon.
Blast Fur. & St. Pl., Sept., 1923; v. 11, pp. 469-471.
(Characteristics of fans operated under different conditions. Serial.)

Electric Drive—Paper Mills

Motor Drive and Control Requirements for Paper-mill Beaters. Cordes, O. C.
Elec. Wld., Sept. 22, 1923; v. 82, pp. 611-612.

Electric Drive Pumps

Revolutionizing Mine Pumping with Automatically Primed, Started and Controlled Centrifugal Pumps. Gealy, Edgar.
Coal Age, Sept. 13, 1923; v. 24, pp. 392-396.
(Describes an automatic electric-drive pumping installation of the Philadelphia and Reading Coal and Iron Co.)

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Direct-connected Induction Motors vs. Geared Motors for Rolling Iron and Steel. Barnholdt, H. L.
Elec. Jour., Sept., 1923; v. 20, pp. 314-317.

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Speed Regulator for Individual-motor Reel Drive. Ashbaugh, J. H.
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(Describes a regulator for motors driving wire reels in a steel mill.)

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Applying the Induction Furnace to an Industrial Brass Foundry. Crawford, J. G.
Elec. Wld., Sept. 22, 1923; v. 82, pp. 586-588.

Electric Heating

Facts About Electric Heating. Whelen, M. P.
Elec. News, Sept. 15, 1923; v. 32, pp. 78-80.
("Results of special research on the application of electrical heating systems to dwellings.")

Electric Meters

Meter for Recording Transformer Losses. (In German.)
Elektro-Jour., Aug.-Sept., 1923; v. 3, pp. 179-180.
(Describes a three-phase meter for use in determining transformer and line losses in high-tension installations.)

Electric Meters—Testing

Calibration of Test Meters. Knowlton, A. E.
Elec. Wld., Sept. 29, 1923; v. 82, pp. 645-647.
(Describes equipment and methods used in the laboratory maintained by the Public Utilities Commission of Connecticut, at Yale University.)

Electric Motors, Induction

Operation of Induction Motors with External EMF's Impressed on the Rotor Circuit. Cotton, H.
Beama, Sept., 1923; v. 13, pp. 167-174.
(Serial.)

Electric Transformers

Causes and Prevention of Explosions in Power Transformers. Eschholz, O. H.
Elec. Wld., Sept. 1, 1923; v. 82, pp. 423-425.

Electric Transformers, Instrument Type

How to Check Instrument Transformer and Meter Connections. Todd, Victor H.
Power, Sept. 11, 1923; v. 58, pp. 413-415.

Electric Transmission

Interconnection Progress in Ohio at 132,000 Volts. Snider, George E., and Spracklen, E. E.
Elec. Wld., Sept. 8, 1923; v. 82, pp. 484-486.

Electric Welding

Welding Cast Iron with a Special Nickel Copper Alloy Welding Wire. Churchward, Alexander.
Am. Weld. Soc. Jour., Sept., 1923; v. 2, pp. 17-19.

Welding of Alloy Steels. Holslag, C. J.
Am. Weld. Soc. Jour., Sept., 1923; v. 2, pp. 9-12.

Electrical Machinery—Accidents

Equipment Failures in England.
Elec. Wld., Sept. 8, 1923; v. 82, p. 487.
(Digest of a portion of the 1922 report of the British Engine, Boiler & Electrical Co., Ltd., on turbine and generator failures.)

Electrical Machinery—Temperature

Temperature Rise in Copper Conductors on Momentary High Current Densities. Gittins, G. E.
Met.-Vick. Gaz., Aug., 1923; v. 7, pp. 329-330.
(Brief article on methods of computation.)

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Producing Synthetic Gray Iron in the Electric Furnace. Willson, Edwin L.
Elec. Wld., Sept. 1, 1923; v. 82, pp. 431-433.
(Results of experiments conducted by the Hartford Electric Light Co., and the Connecticut Electric Steel Co.)

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Development of the Modern Gear. Phillips W. H.
Elec. Rwy. Jour., Sept. 15, 1923; v. 62, pp. 413-414.
(Abstract of a paper on street railway car gears.)

Generators, D-C.

Continuous-current Generator for High Voltage. Bergman, S. R.
A.I.E.E. Jour., Oct., 1923; v. 42, pp. 1041-1045.
(Illustrated description of construction.)

Governors

Recording Hydraulic-turbine Governor Operation with an Oscillograph.
Power, Sept. 18, 1923; v. 58. pp. 446-447.
(An account of tests at the Holtwood, Pa., plant of the Pennsylvania Water and Power Co. Serial.)

Heat Insulation

Insulation of Cold Surfaces to Prevent Sweating. Barrett, L. L.
Power Pl. Engng., Sept. 1, 1923; v. 27, pp. 870-872.
(Presents methods of calculating the insulation required under various conditions of temperature and humidity.)

Hydroelectric Development

Detailed Estimate of the Cost of Davis Bridge Development.
Elec. Wld., Sept. 15, 1923; v. 82, pp. 532-533.
(Consists essentially of tabulated and other statistics on the cost of the New England Power Company's new hydroelectric plant at Davis Bridge, Vt.)

Insulation

Comparison of Properties of Hard Rubber, Vulcanized Fiber and Laminated and Molded Phenolic Insulating Materials.
Elec. Wld., Sept. 15, 1923; v. 82, pp. 544-545.
(Tabulated comparison, as shown in U. S. Standards Bureau Technologic Paper No. 216.)

Lightning Arresters

Pellet Type of Oxide Film Lightning Arrester. Lougee, N. A.
A.I.E.E. Jour., Oct., 1923; v. 42, pp. 1019-1020.
(Short illustrated description.)

Machinery—Erection

Accurate Methods of Aligning Steam Turbines—Using Sound to Increase Sensitiveness of Measurements. Barker, Sr., Edgar G.
Power, Oct. 2, 1923; v. 58, pp. 526-527.

Machinery—Inspection

Care of Power Transformers. Brown, Ralph.
Power, Oct. 2, 1923; v. 58, pp. 522-524.

Planimeters

Why You Can Measure the Area of an Indicator Diagram by a Planimeter.
Power, Oct. 2, 1923; v. 58, pp. 524-525.
(Elementary explanation of the theory of the planimeter.)

Power Plants—Testing

Study of Power-station Efficiencies. Marshall, C. W.
Elec. Rev. (London), Sept. 21, 1923; v. 93, pp. 439-440.
(Short article summarizing the essentials of test procedure.)

Power-factor

Remotorizing Plant Raises Power-factor. Henschel, O. H.
Power Pl. Engng., Sept. 1, 1923; v. 27, pp. 883-887.
(Describes changes in motor equipment in a steel finishing plant which resulted in marked improvement in power-factor.)

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Protective Features of Current Limiting Reactors. Knotts, C. L.
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Electric Transmission of Power for Propelling Machinery. Belsey, W. J.
Inst. Engrs. & Shipbuilders Trans., Sept., 1923; v. 66, pp. 76-131.
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Simplified Method of Analyzing Short-circuit Problems. Doherty, R. E.
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Steam Boilers, Electric

Generation of Steam by Electricity. Falter, Philip H.
Blast Fur. & St. Pl., Sept., 1923; v. 11, pp. 500-503.

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Exhaust Steam Turned to Profit.
Power Pl. Engng., Sept. 15, 1923; v. 27, pp. 911-917.
(Describes methods used in the power plant of the H. C. Godman Co., Columbus, Ohio.)

High-pressure Steam Systems. Jacobus, D. S.
Elec. Wld., Oct. 6, 1923; v. 82, pp. 699-701.
(Design and arrangement of boilers, economizers and superheaters; automatic temperature control.)

Steam Turbines

Devices to Reduce Leaving Losses in Steam Turbines. Cox, Ivor R
Beama, Sept., 1923; v. 13, pp. 175-181.
(Describes several different designs.)

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Prevention of Excessive Increases of Pressure in Steam Turbines. Baur, A.
Brown Boveri Rev., Sept., 1923; v. 10, pp. 174-175.
(Short description of a B. B. C. device.)

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Bearing Currents and Their Suppression. Fraenckel, A.
Elec. Rev. (London), Oct. 5, 1923; v. 93, pp. 488-489.

Substations, Automatic

Direct-current Automatic Substation as a Labor-Saving Device for Steel Mills. Wilson, G. P.
Elec. Jour., Sept., 1923; v. 20, pp. 337-339.

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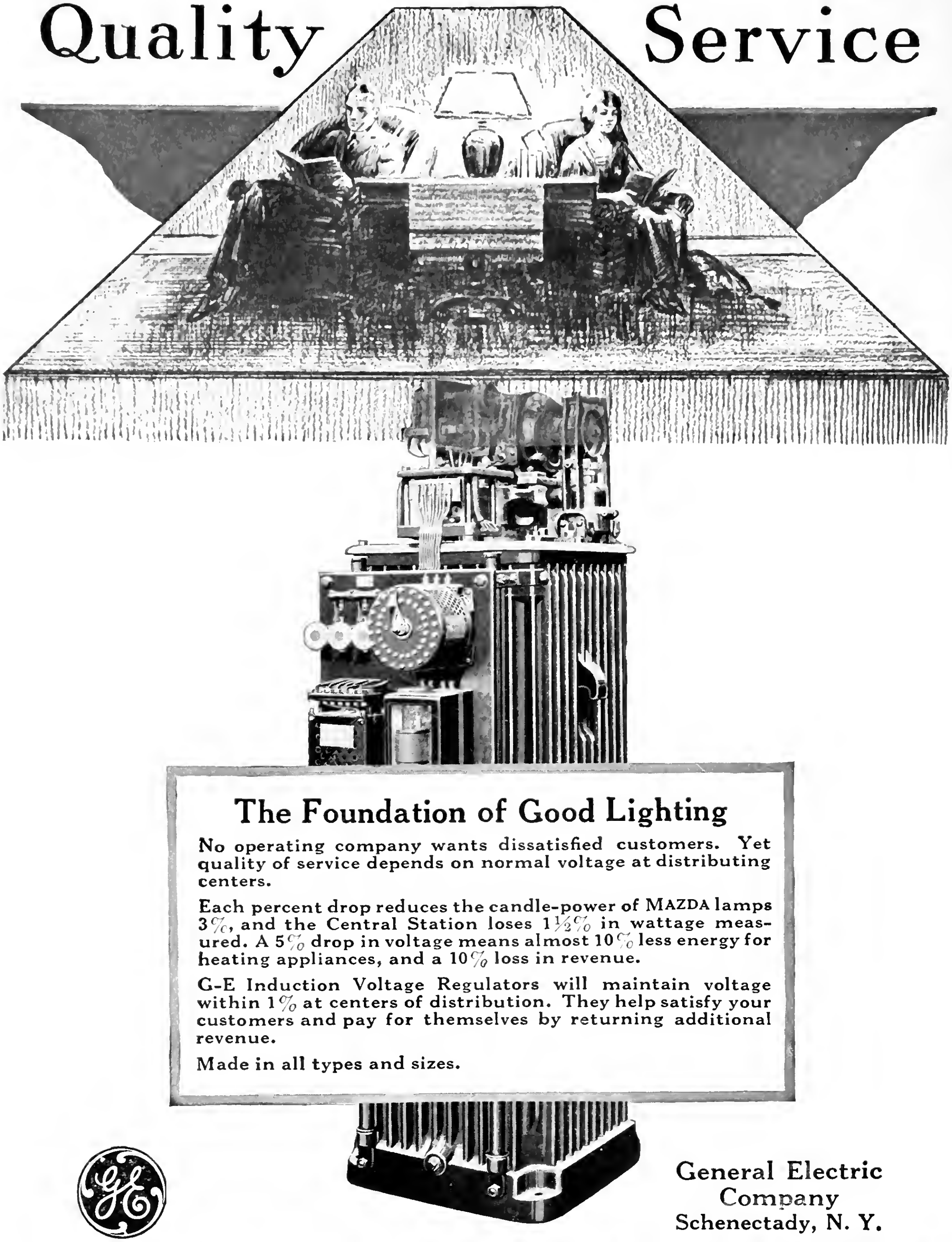
Survey of the Milwaukee Market on Household Appliances. The Milwaukee Journal. 333 pp., 1923, Milwaukee. The Milwaukee Journal.

Quality Service



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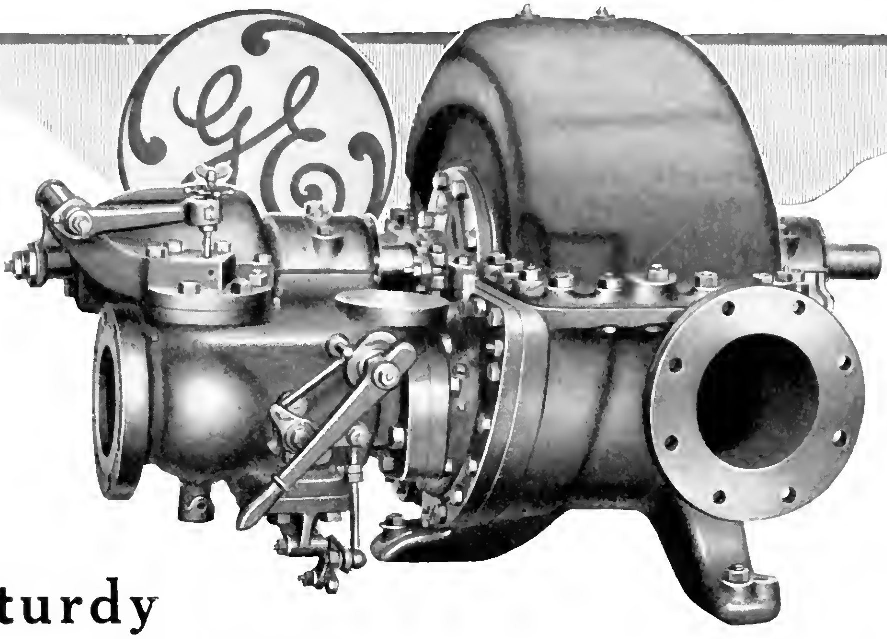

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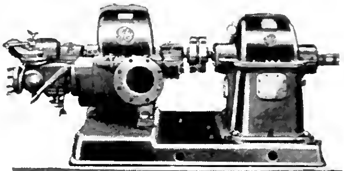
Ask any G-E Sales Offices for information on Steam Turbines for any service.



This G-E Turbine and Reduction Gear is just the right combination for medium- and low-speed drives: centrifugal pumps, fans, blowers, compressors and similar apparatus. The gear makes it practicable to operate both the turbine and the driven machine at speeds productive of best efficiency.

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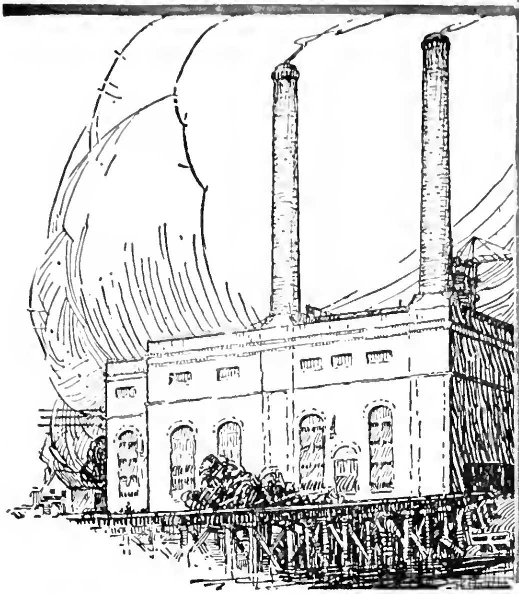
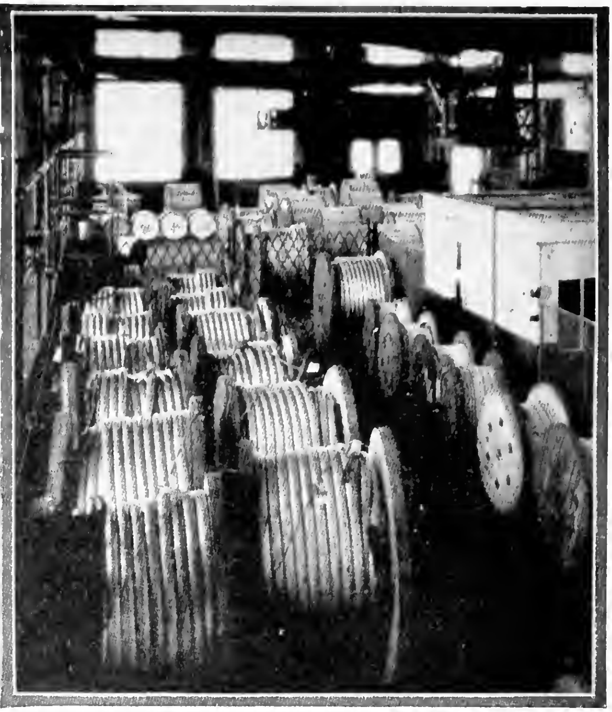
31[illegible]B

For Light and Power





Section of G-E Wire and Cable Testing Department

Cables that Insure Transmission Service

It is a significant fact that G-E Wires and Cables have been specified for many of the world's largest engineering developments where the essential is continuous operation over a long term of years.

The General Electric Company manufactures all sizes and types of wire and cable for lighting and power service.

General Electric Company
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GENERAL ELECTRIC

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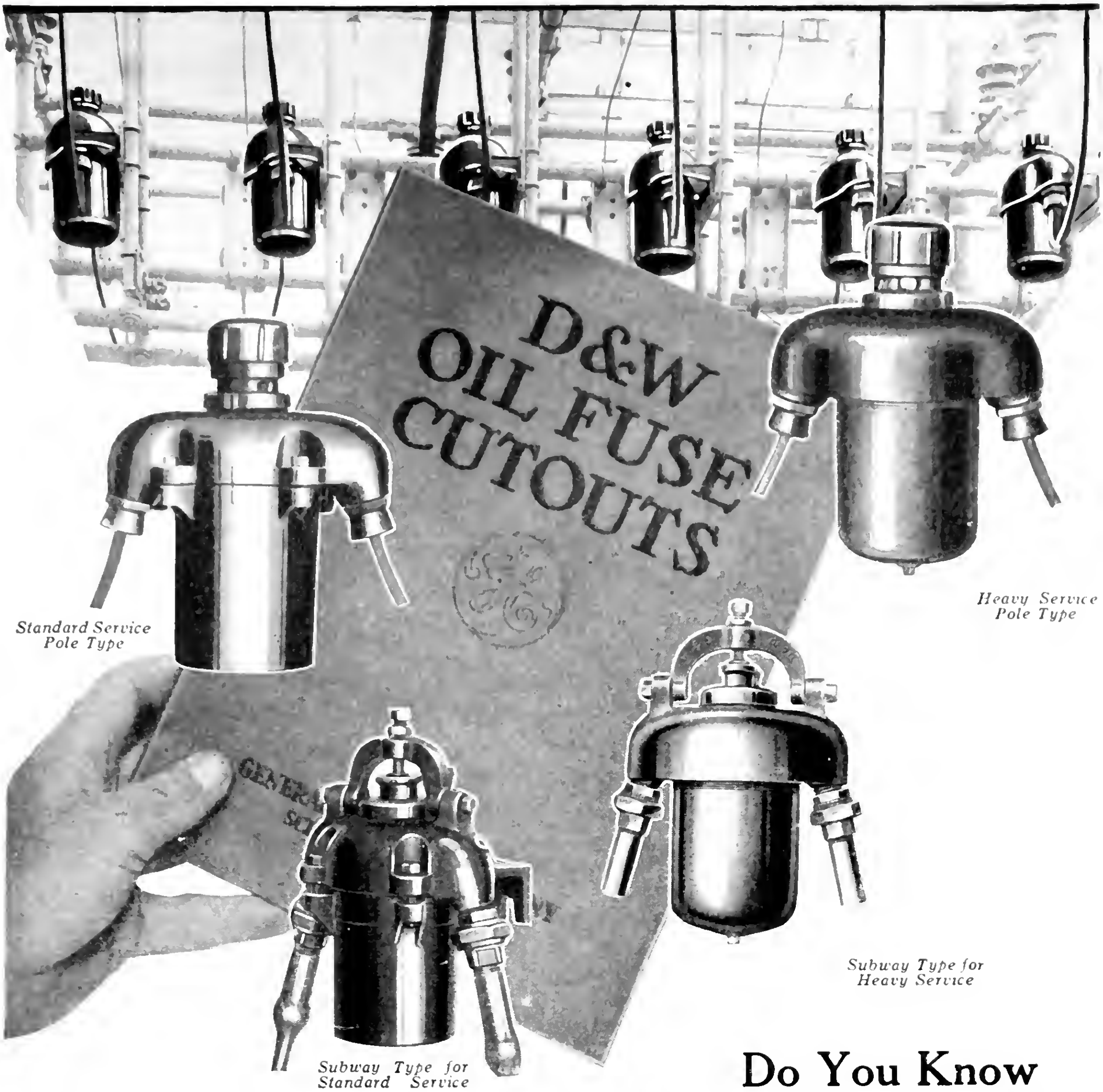

Standard Service Pole Type

Heavy Service Pole Type

Subway Type for Heavy Service

Subway Type for Standard Service

Do You Know Their Wide Application?

The new revised edition of Catalog No. 6004 gives the latest information. Do you wish a copy?

For protecting small, important transformer substations and all transformers located in the vicinity of stations where large amounts of power may require interrupting.

For fusing tap-offs, sectionalizing feeders, and fusing outgoing secondary circuits of substations.

D&W Oil Fuse Cutouts can protect against overloads, and yet their rupturing capacity is very high. Their uniformity and accuracy of blowing are exceptional.

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GENERAL ELECTRIC

33A-1 B

I-14

Watthour Meters

Accuracy in Service

The standard by which a watthour meter should be judged is not its performance under ideal conditions. What is its accuracy under the less favorable conditions such as: inductive loads, varying voltage, frequency or temperature and abnormal wave forms? And will it maintain its initial accuracy indefinitely?

The I-14 Meter fulfills these requirements. Its freedom from the effects of these abnormal conditions and its ability to maintain its high initial accuracy over a continued period of service, simplifies the meter problem of the central station.

Ten years of successful service shows the I-14 Meter to be as nearly perfect as present day experts in meter design and manufacture can produce. It represents the culmination of a long period of development by the General Electric Company, which has 35 years of experience in watthour meter building.

General Electric Company
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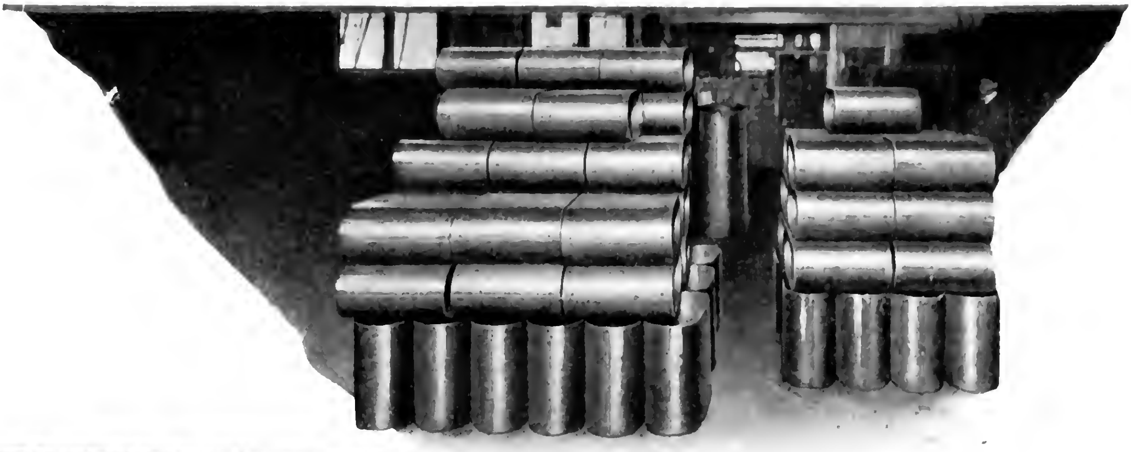
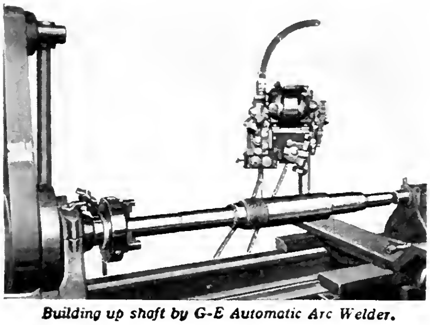
34A-34B



Straight seam welding of tanks by G-E Automatic Arc Welder.



Building up shaft by G-E Automatic Arc Welder.

Automatic Arc Welding

The above picture shows 50 tanks welded by a G-E Automatic Arc Welder in a half day, as compared to 21 tanks welded by the hand method in a full day. The metal welded is 1/8″ thick by 24″ long.

Through this automatic application of the electric arc, a steadiness of the electrical conditions in the arc is obtained and maintained, resulting in a uniform and high quality of weld—and higher speed. Higher welding speeds produce lower welding costs.

The principal field for the G-E Automatic Arc Welder is the production, by welding, of duplicate objects in considerable quantities.

Its greatest use is for straight line seam, which is the simplest form of weld—but it also does efficient welding of circular seams, and in building up processes on metal.

G-E welding engineers will cooperate with you in making suitable applications of the Automatic Arc Welder to processes of production in your plant. Ask them.

General Electric Company
Schenectady, N. Y.
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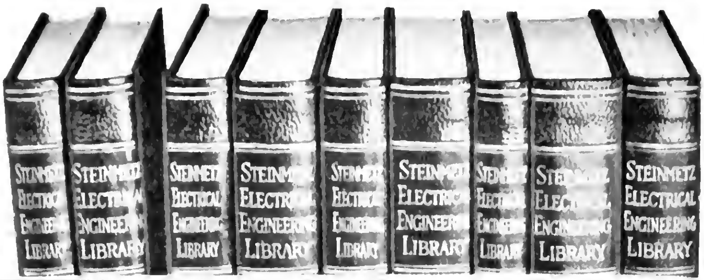

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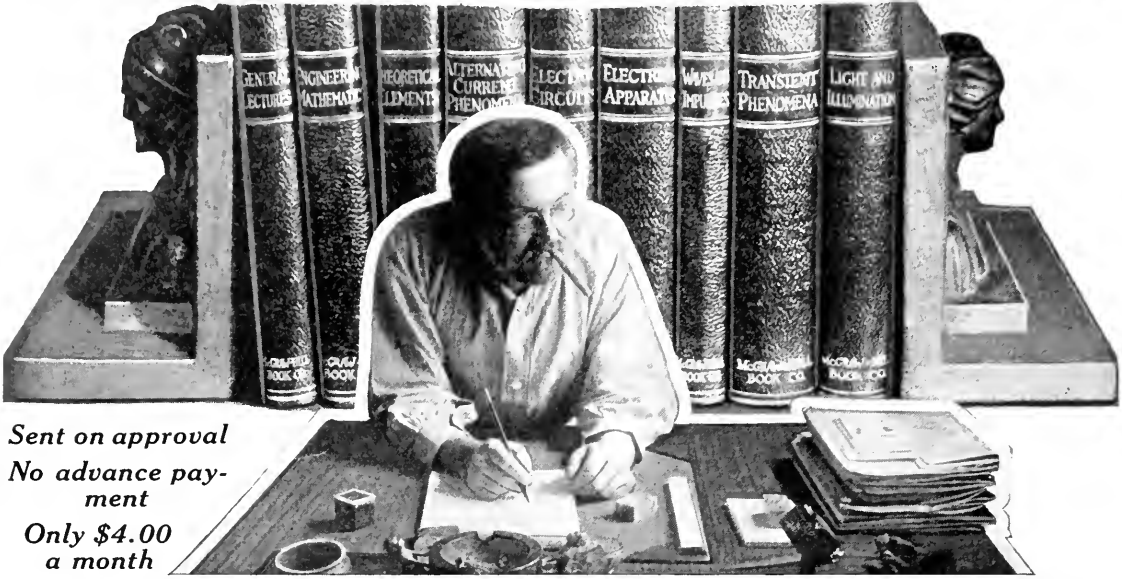

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"Nobody can estimate the extent to which Dr. Steinmetz's research, as given in his books, has served as the cornerstone and foundation of modern electrical practice."

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"I'll go a step further. If all the knowledge and equipment of electrical engineering were to be wiped out, except Dr. Steinmetz's books, both the science and industry could be rebuilt with the aid of these books."

The cornerstone and foundation of modern electrical engineering knowledge—that is literally what the STEINMETZ BOOKS are. They are the classics of electrical engineering.

Put these engineering classics in your library

The nine volumes which Dr. Steinmetz has contributed on the subject of electrical engineering are now available in a handsome specially bound set.

Have this set with its full treatment of the theory and special problems of electrical engineering at your command. The handbook and the practical treatise may give you the simple fact you need—but Steinmetz gives you the theory and its application—the real solution of the problem.

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G.E. 12-23

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Announcing a Big HOOVER

for Hotels
Clubs
Offices
Stores
Large Homes
etc., etc.

Partial view of the wonderful new Hoover, Model 961. Sturdy and durable. Requires no oiling. Quiet running. Easy to operate. Ball bearings throughout. Weighs only 29 pounds. Retails at $135, east of Rockies. Attachments, $15.

After several years of experimentation and study, the new big Hoover, Model 961, is ready.

It combines the best engineering and manufacturing practices of the day. It is made possible by an accomplishment in motor building never before attempted in portable cleaners.

This big, sturdy, moderately priced new Hoover introduces a new era in the sale of electric cleaning apparatus for use in large residences, dormitories, institutions, stores and fine shops, as well as hotels, clubs and offices.

There is nothing to rival it, either for eco omy or efficiency. It far surpasses all install plants. It outclasses all other portable cleane Since it was designed particularly for continous heavy work, it does such work better, faster and easier than any other existing method.

Practically "Fool Proof"

This new Hoover can be safely placed in the hands of ordinary help. Rough treatment or neglect cannot [illegible] It is built for daily usage [illegible] no skill [illegible] red.

No Oiling Required

Not a drop of oil is ever necessary anywhere. Forgetting to oil the motor can never cause trouble. This new quiet-running Hoover has a *ball*-bearing, *dust-proof* motor made especially for us by the General Electric Company.

Electrical Merchandising Pictorial, July, 1922

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Factories at North Canton, Ohio, and Hamilton, Canada

The HOOVER
It BEATS.....as it Sweeps as it Cleans

Electrical Merchandising Pictorial July 1922

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we have made this year

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So, therefore, those who are interested in Power Plants will be pleased to learn that the November issue of *Lubrication* contains an article entitled:

"STEAM POWER PLANT PRIME MOVERS AND THEIR LUBRICATION"

This article deals with the lubrication of steam engines, internally and externally, and with various types of steam turbines.

It discusses tersely, yet completely, effective lubrication methods and gives a guide to the selection of correct lubricants.

The entire 12 pages are devoted exclusively to the various phases of this big subject.

We expect a big demand for this issue and, therefore, we are going to make this announcement *once only*. Requests will be filled in the order of their receipt as long as the supply lasts.

Those who read this announcement and are already receiving *Lubrication* may wish to call it to the attention of colleagues and friends who do not get it.

We are sending out *Lubrication* free because we believe it will encourage the use of better lubricants—and Texaco Lubricants are better lubricants.

There will be no salesman following up your request. When you receive the magazine *Lubrication*, that ends the matter.

—Unless you, yourself, feel that your plant will benefit through Texaco Service—and call on us to demonstrate.

So, then, that's understood and here's the coupon that brings you, while they last, what we are pleased to think the best issue of our magazine *Lubrication* so far published.

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12-23

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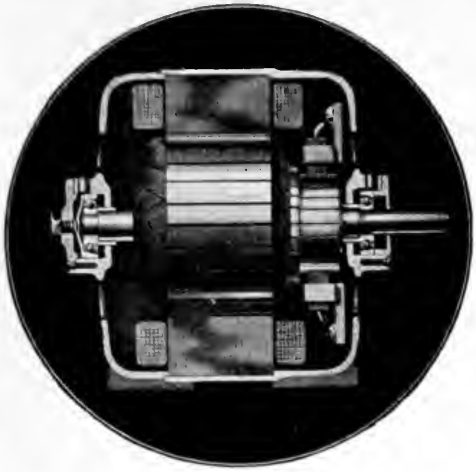


HYDRO-ELECTRIC POWER STATIONS
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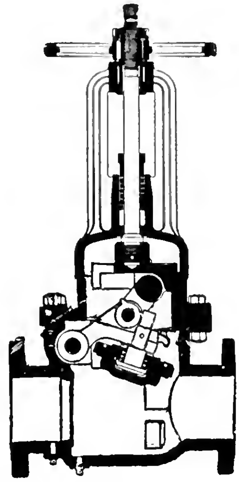

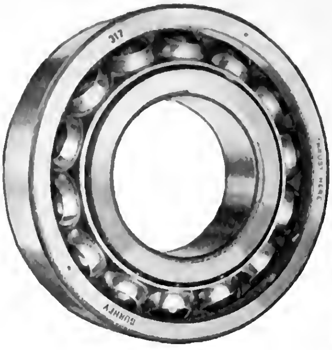

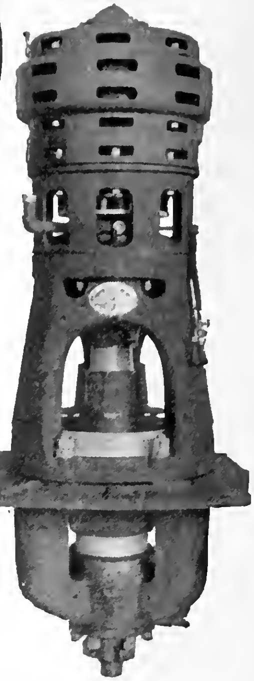

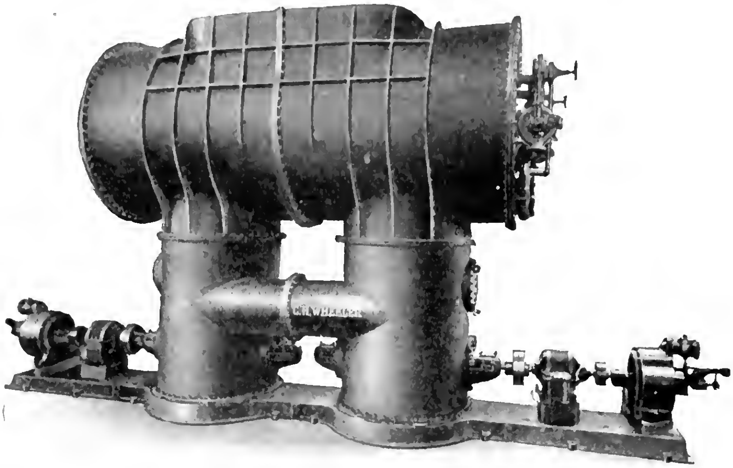

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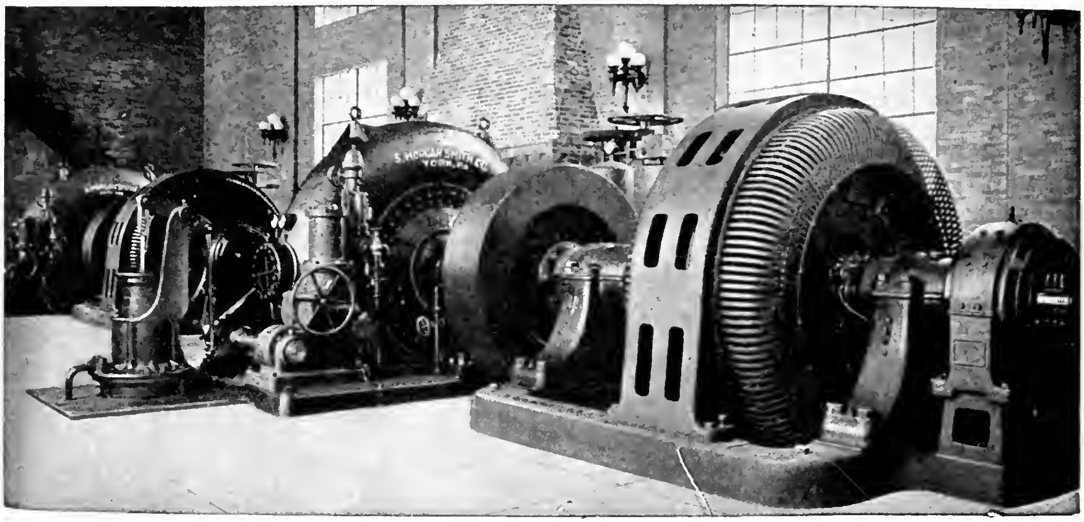

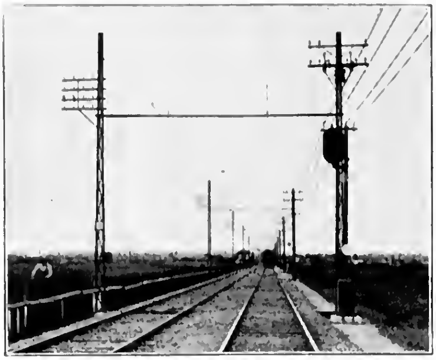

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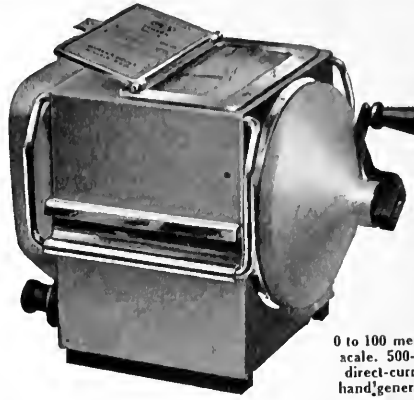

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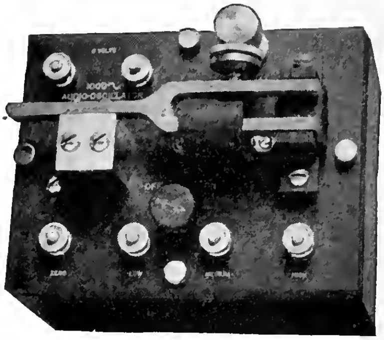

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Circuit Diagram and Complete Description in Bulletin 706 G

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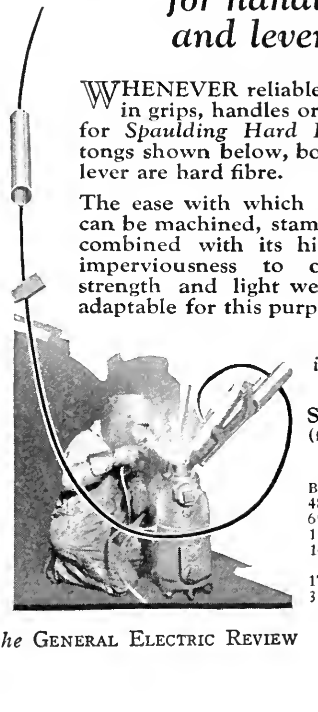

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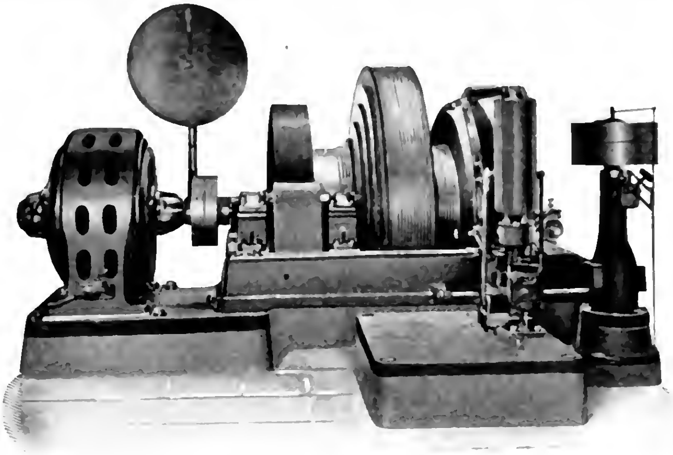

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THE SILSBEE CURRENT TRANSFORMER TESTING SET

is a compact *portable* set for making precision tests of current transformers in position. Checks ratio and phase angle.

Described in Bulletin 715 G

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